

SIMULATION OF TRAFFIC AT INTERSECTIONS

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in Partial Fulfilment of the Requirements
for the Degree of
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by

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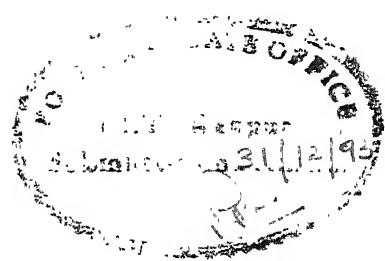
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December 30 , 1993

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DEDICATED
TO MY
LOVING GRANDFATHER

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ABSTRACT

Intersections in highway and street networks are of importance to the traffic engineer who is responsible for design and operation of these facilities. They are normally a major bottleneck for smooth flow of traffic and major accidents and traffic delays take place on these locations. Thus there is need to have properly designed intersections both on rural sections of highways and in urban areas.

Unsignalised intersections are the most common intersection type. Yet, they are least understood and the techniques to analyse their performance are being developed continuously. This is a function of their complexity. The performance of an intersection is greatly influenced by the capacity of intersection, types of vehicle, turning movements, desired speed of vehicles, acceleration and deceleration capabilities of vehicles, driver's judgement and on the stochastic characteristic of traffic flow process. Therefore, traffic engineers have used the tool of modeling to understand and analyse the complex behaviour of traffic at an intersection.

A number of analytical models have been used for the above purpose, but these are complex and are for simple situations. It however, seems possible to simulate the process on digital computers.

The objective of this study was to develop a simulation model of traffic at intersections which could be used to evaluate the intersection performance in terms of traffic delay, or the travel time of the users of traffic system and practical capacities of an intersection. Simulation models have been developed both for T-intersection (priority intersection) and four

way stop sign intersection (uncontrolled). Measures of effectiveness are in terms of average delay to individual vehicles, number of vehicles that are stopped, queue lengths and number of times a driver can be expected to move-up in the queue. These measures can be used to predict the fuel consumption of vehicles and capacity of an intersection. The formulation has been made in a manner such that measures of effectiveness can be determined for any combination of traffic flow on either lane, for any gap acceptance criteria, and for any combination of turning movements. In this study four intersections namely Kalyanpur T-intersection, Hanuman Mandir T-junction, Kidwainagar crossing and Site No.1 crossing have been considered for validation of the simulation model.

It has been found that average delay to traffic for some intersections is very high, as in real world situations some vehicles like bicycle does not follow the assumptions of the model (i.e. all vehicles are moving in queue etc.) and move to front of queue through a self made lane. The model was then modified and a separate lane was provided for bicycle traffic which seems more close to real life situations. Average delay for each vehicle as obtained by modified model is close to that experienced in the field, thus validating the model. Fuel consumption model for an intersection has been indicated in terms of delay components (i.e. deceleration delay, queueing delay, and looking for gap delay). Intersection capacity is also found from the model using total volume versus average delay variation for all types of intersection. The computer programming language used in developing the model is Pascal and implemented on HP 9000 system of I.I.T. Kanpur.

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CHAPTER ONE

INTRODUCTION

1.1 GENERAL

Traffic engineering is that branch of engineering which deals with the improvement of traffic performance of road network and terminals. With the continuous increase in population and corresponding growth of vehicles, the road network has come under a heavy strain in most of major cities and interurban highway system. Hence there is need for updating highway network for safe, rapid and efficient movements.

Intersections in highway and street networks are of importance to the traffic engineer who is responsible for design and operation of these facilities. They are normally a major bottleneck for smooth flow of traffic and major accidents and traffic delays takes place on these locations. Studies in India and abroad have shown that as much as 25 to 33% of total accidents occur at intersections. This exemplifies the need to have properly designed intersections both on rural sections of highways and on urban areas.

In India most of highway network links (both in rural and urban areas) are located at grade and they frequently intersect, thus leading to conflicts between crossing flows of

traffic, which results in delays and accidents. Intersection plays an important role in determining the overall capacity and performance of highway networks. Therefore traffic engineers are continuously facing with the problem of controlling flows at intersection in order to improve the overall performance of highway network. However, this problem is complicated by the fact that each intersection has unique characteristics of physical layout, vehicle flow patterns, turning movements, pedestrian movements etc.

Broadly intersections can be divided into two categories-

(i) Unsignalised intersections (uncontrolled)

(ii) Signalised intersections (controlled)

Unsignalised intersection can be further divided into three types -

(i) Uncontrolled intersections

(ii) Priority intersections

(iii) Space-sharing intersections

Signalised intersections are those at which alternate flows are given the right of way at different points in time. Typically these intersections are controlled by traffic signals or by police officers. Though traffic signals form a suitable way of traffic control at many existing urban or rural intersections they are not appropriate for implementation at all locations. There are many intersections where minor road flow levels are such that they

do not warrant signalised control. Intersections with heavy turning movements can be controlled efficiently by channelisation methods than by signals since the prime function of an intersection is to accommodate the demand for movement and which of the methods is to be adopted is a question for traffic engineers to operate the vehicles safely on all the roads efficiently.

1.2 STATEMENT OF THE PROBLEM

Unsignalised intersections are the most common intersection type in the world. Yet, they are least understood and the techniques to analyse their performance are being developed continuously. This is a function of their complexity. The simplest form of road intersection design is by far the most common and depends on the priority to traffic movements to one road over the other. Traffic from the minor road controlled by stop sign or yield sign must wait for a reasonable or acceptable gap in the major road traffic before crossing it and/or merging with it. It is generally assumed that virtually no delays occur to the major road flow or main highway traffic. But of course if delays to side street traffic increase significantly, regulation may be violated and may result in delays for both major and minor streams of traffic. But problem arises in uncontrolled intersections where the intersecting roads are of relatively equal importance and when traffic volumes are so light that no form of control or redesign

appears necessary. However, it is generally assumed that whenever conflicts do occur right of way is assigned to vehicles on the right, thus forcing one vehicle to be delayed in preference to another. Four way uncontrolled intersection are ambiguous where two major roads intersect. Priority intersections can be exemplified by T-intersections where a minor road meets a major road and finally the ramp intersection where a vehicle of minor road merges with the major road.

The operation of unsignalised intersection is a complex phenomenon and therefore, determination of its performance by analytical method is not possible in most of the situations. Moreover it does not seem possible to solve for the behaviour and performance of intersection because of complex logical and probabilistic characteristics of traffic flow process. It however seems possible to simulate the process on a digital computer.

1.3 UNSIGNALISED INTERSECTION

One of these types, the unsignalised intersections namely uncontrolled intersection, priority intersection and ramp intersection are being modeled and simulated, and average delay to individual vehicles crossing intersections has been calculated.

At uncontrolled intersections the arrival rates and individual drivers generally determine the manner of operation, while the resulting performance characteristics are derived from joint consideration of flow conditions and driver judgements and

behaviour patterns. In simplest terms, at an intersection, one flow of traffic seeks gaps in opposing flow of traffic. But at priority intersections, since one flow is given priority over the right of way, it is clear that the minor flow is usually the one "seeking gaps." By contrast, at an uncontrolled intersection, each flow must seek gaps in the other opposing flow. When flows are very light, which is the case on most urban and rural roads, large gaps exist in the flows and thus few situations arise when vehicles arrive at intersection in a platoon where gaps are very less. However, when vehicles arrive at the uncontrolled intersection only a few seconds apart, potential conflicts exist and drivers must judge their relative time relationships and adjust accordingly. Generally one or both vehicles must adjust their speeds (and be delayed somewhat), with the closer vehicle most often taking the right of way; in a sense, of course, the earlier arriving vehicle has "priority" (both by custom and law, in most cases) and in those instances when two vehicles arrive simultaneously, the rules of road usually indicate "priority" for the driver on the right. So delays to individual vehicles depend on flow (traffic volume, turning movement and geometric design of intersection) and on driver's judgement. Total intersection delay will normally increases as traffic volumes increase, the introduction of some form of priority control will probably reduce total intersection delay (but almost certainly increase the minor-stream delay) if intersecting flows are unbalanced. The stop

sign is one common method of denoting priority at an uncontrolled intersection, and its introduction is also likely to reduce the number of accidents (since right of way or priority is established) even though the number of possible conflicts does not reduce. At priority intersections delay to side street vehicles is directly related to the size of the time gap a driver thinks he needs to pass through the main stream and to the number of gaps equal to or larger than this required or acceptable gap. The number of gaps of this size is related to the main highway volume. So one should incorporate all the above problems in the intersection model.

1.4 OBJECTIVE OF THE STUDY

The objective of this study was to develop a simulation model of traffic at intersections which could be used to evaluate the intersection performance in term of traffic delay, or the travel time of the users of traffic system. Capacities of an intersection can also be determined by this study under various traffic and operating conditions. This can be achieved with the help of by calculating the aggregate delay to all the users of a traffic system. Practical capacity is defined as "the maximum number of vehicles that can pass a given point on a roadway or in a designed lane during one hour without the traffic density being so great as to cause unreasonable delay, hazard or restriction to the driver's freedom to maneuver under the prevailing roadway and traffic conditions".

The operation of intersection is greatly influenced by the total traffic volume, type of vehicles, turning movements present in the stream, desired speed of vehicles and acceleration or deceleration capabilities of the vehicles. Because of large variations of these quantities, flows are incorporated randomly and simulation model is structured to account for these variations. It is hoped that the findings of these study will contribute to the understanding of this complex urban traffic problems.

1.5 METHODOLOGY

A simulation modeling study is essentially a statistical experiment, requiring appropriate tools for the collection and analysis of data. The facility under study identified as the system. Basic operations involved are the arrival, departure and queueing pattern of vehicles approaching an intersection.

To model a system is to replace it by something which is simpler and easier to study and equivalent to that of the original one in all important respects. If the real system interacts with the outside world in some way, that interaction must also be reflected in the model.

The approach presented for solution of vehicles performance at intersection is a stochastic numerical modeling method. The behaviour of the simulated system is influenced by random events occurring at different moments in time. The

simulation is carried by generating these events in a digital computer, observing the resulting behaviour of the system and obtaining estimates for the required measure of performance.

The question may arise as to why use digital computer simulation and why not closed form solution. Models with random arrivals (negative exponentially distributed) give simpler equation for the transition between states. For other type of distribution or other types of model such as multiple channel model single channel model, continuum model etc., it is very difficult to treat them mathematically because the set of equations are usually much more complicated and in general they cannot be solved explicitly in terms of simple mathematical functions. In these cases, it is necessary to resort to simulate the process. One may wish to estimate the performance of a system which is not built. Alternatively the object may be to assess the effect of a major change in an existing system. In such cases simulation is helpful.

Simulation undertaken manually are very time consuming. Each run or experiment is itself a tedious task, and several repetitions of each run are usually required so that variance estimate can be made. Consequently it is natural that simulation should be performed by digital computers.

1.6 CONSTRUCTION OF SIMULATION MODEL

In order to construct a simulation model, it is

necessary to abstract from the real system all those components and interactions which are considered important enough for inclusion in the model. The components thus selected are reflected as entities. In the simulation of unsignalised intersection the entities might be road vehicles movement, any type of control, turning associated with each entry are attributes that describe the state of entity. Attributes of road vehicle is their speed, identification numbers and their types. The collection of attributes at any time defines the system state. Change of state in course of operation path is called an event.

The system state mentioned above is a function of time. In this study simulation of discrete event system with variable time increments based upon process oriented approach have been considered. Operation path of a system is regarded as resulting from the interaction of a number of process running in parallel. A process is defined as a sequence of events, together with a set of actions accompanying each event. These processes of unsignalised intersection model reported in this thesis have been simulated using computer language PASCAL which also one of the versatile language for simulation other than SIMULA.

1.7 STUDY METHODOLOGY

In the present study, due to complexity involved at an unsignalised intersection due to heterogeneous nature of traffic and different road conditions, and non availability of the closed

form solution, it has been decided to simulate the system. Simulation allows an in depth study of the real problem and at every step its interaction with other entities of the system are known. A discrete event simulation model based on queueing theory concept has been developed. The computer program PASCAL language has been structured for the problem and implemented on HP-9000 system at the Computer Center of I.I.T. Kanpur.

Data at unsignalised intersection is needed to use as input to the model and for validation of the model. This data has been collected for case study of intersection at Kalyanpur T intersection on G.T. Road which is around 2 km from I.I.T. Kanpur and around 16 km from railway station. Data for other intersection i.e Hanuman T-junction (at intersection of Kalpi road and Panki Mandir road), Kidwai Nagar crossing, and Site no.1 crossing are taken from NATPAC study for Kanpur city.

The duration of simulation period is taken as half an hour. Then this model is validated using average delay to vehicles on intersection as a parameter for validation. Once the model is validated, it is used for forecasting performance of an intersection for any combination of traffic flow.

1.8 SCOPE OF THE STUDY

The subject under study is very broad. Furthermore, there are limitations of availability of data. The scope of this study was thus restricted to the following:

1. This model is simulated for unsignalised intersection only.
2. This model is not validated for data of intersection in rural areas.
3. Pedestrians interference to vehicles at intersection is not considered in this study.
4. This model is simulated for an area in plain terrain only.

CHAPTER TWO

LITERATURE REVIEW

2.1 GENERAL

A desirable goal for a transportation engineer is to design and operate facilities that minimize delay to users. Delay resulting from congestion is a common phenomenon associated with many types of transportation problems. How long a user must wait, or what is the number of units waiting in line or the proportion of time the facility must be inactive? The answer of above problem was a big challenge for transportation engineers.

Treatment of intersection problem using queueing theory may be categorised by two elements:

- (1) the type of control (stop sign, yield sign, fixed sign signal, or traffic actuated signal) and,
- (2) the element controlled (vehicle or pedestrian)

At the stop sign controlled intersection, it is assumed that the minor road traffic waits for a sufficient gap in the major road traffic before crossing.

The problem of crossing the main street will be considered for both pedestrians and vehicles. There is a fundamental difference between these two cases. Pedestrians arrive at curb until an opportunity to cross present itself. The entire

group then crosses together, independent of the number of pedestrians waiting. Whereas in other case, later vehicle arrivals cannot cross the major road until the first vehicle in line has departed. If minor road vehicular flow is so slow that two or more vehicles will rarely be waiting, the calculation of delays to individual vehicles will be similar to those used for individual pedestrians.

A number of models were formulated for the above problem. Most of the earlier studies are designed to develop empirical relationships. Both theoretical and simulation techniques have been employed to develop models which describe the flow of traffic on highways. Some of the models are described here.

2.2 ANALYTICAL MODEL

An analytical traffic flow model is specified by a set of equations which describe the behaviour of vehicles. The analytical model may be classified as microscopic model or macroscopic. The microscopic model concerned primly with behaviour of a single vehicle and its interaction with the traffic stream. In macroscopic models, emphasis is placed on modeling the characteristics of the entire traffic stream under steady state conditions.

Past research on intersection problem yielded formulas for the calculation of mean queue length and delays for vehicles

on the minor roads which are obliged to give way to the major road vehicle.

One of the earliest theoretical model for unsignalised intersection was developed by ADAMS^[1] in 1936, in which a problem of pedestrians delay at unsignalised intersection was studied and several delay relationships were derived. He assumed that pedestrian and vehicular arrivals are random. If the flow at main street is q (veh/sec.) and critical gap between successive arrival is τ then

Probability of a pedestrian will pass without delay is

$$P(h > \tau) = e^{-q\tau} \quad \dots \dots \text{Eqn. 2.1}$$

Probability that pedestrian will be delayed is

$$P_d = 1 - e^{-q\tau} \quad \dots \dots \text{Eqn. 2.2}$$

An equation is given for the expected or average delay to pedestrians is

$$\bar{d} = \frac{1}{q e^{-q\tau}} - \frac{1}{q} - \tau \quad \dots \dots \text{Eqn. 2.3}$$

Equations given by Adams are also very useful for computing delays for minor road vehicles at priority intersections.

Tanner^[2] published the results of a comprehensive study of pedestrian crossing delays. His work is an extension of the delay relationship developed by Adams. He considered the varying values of gap acceptance for the different pedestrians and gave some attention to the problem of groups of pedestrians crossing the street. He also compared the delay to pedestrians crossing the

entire traffic at one time and with delay to those stopping in the middle (at medians) when necessary.

Mayne^[3] generalised Tanner's result to include an arbitrary distribution of independent main street headways.

Jewell^[4] obtained the distribution, mean, and variance of waiting times for arbitrary main stream headway distribution and for several main street situations at the time a side street vehicle present itself. In the continuation, Weiss and Maradudin^[5] expressed delay characteristics for several gap acceptance distributions. Herman and Weiss^[6] fitted shifted exponential constants experimentally. The mean delay to side street traffic as developed by Herman and Weiss is:

$$E[t] = \frac{e^{qT} - 1}{q} - \tau + \frac{1}{b} [e^{qT} - 1 - q\tau + \left(\frac{q}{q+b}\right)^2 * (1+q\tau+b\tau) * (1-e^{-q\tau}) + e^{-q\tau} \left(\frac{q}{q+b} + q\tau\right)] \quad \dots \dots \text{Eqn. 2.4}$$

Where

τ is the minimum acceptable gap,

q is main stream flow,

$b = \frac{1}{(T - \tau)}$, where T is mean headway.

Beckmann^[7] have given expression for average total delay to side street vehicle. For this delay model, arrivals were assumed to be binomially distributed and a term maximum density ratio was used. The resulting delay model is as follows:

$$\bar{d}_a = \frac{1 - P(1 + \frac{\rho_1}{\rho_2} t)}{\frac{\rho_1}{\rho_2} (P - \frac{\rho_1}{\rho_2})} \quad \dots \dots \text{Eqn. 2.5}$$

where

\bar{d}_s is average total delay/side street vehicle in time point,

ρ_1 is maximum density ratio for major street flow,

ρ_2 is maximum density ratio for side street flow,

t is critical lag (min. acceptable gap) in time point,

$$P = (1 - \rho_1)^t$$

Here a time point is the largest time interval (in seconds) in which at most only one vehicle arrival can occur and the term maximum density ratio is defined as ratio of the number of 'cars which arrive in a long period of time to the maximum number which could arrive provided the proper time spacing between cars is maintained.

Tanner^[8] derived a formula for the average delay to vehicles on the minor road when the system is in statistical equilibrium. It is assumed that vehicle on the major road and minor road arrive at random and pass through at intervals not less than time β_1 and β_2 respectively. Minor road vehicle can enter the junction within time α after the previous vehicle on the major road. So one minor road vehicle can pass through a gap of duration between α and $\alpha + \beta_2$ and two can pass in gap of between $\alpha + \beta_2$ and $\alpha + 2\beta_2$ and so on. The practical implementation of the results are not discussed, but it is hoped to compare the delays with those obtained with traffic light control.

Glaian and Epstein model derives average speed and average delay for a test vehicle. Vehicles are generated by two

independent Poisson processes.

Kimber^[10] has shown the interrelationship between geometrical delay—"delay caused by the need of isolated vehicles to slow down to negotiate assumption" and the queueing delay due to vehicle-vehicle interaction, and has shown that significant proportion of total delay caused due to geometrical delay, and queueing delay when traffic intensity increases gradually.

Troutbeck^[11] formulated an expression for the average delay at an unsignalized intersection with two major streams each having a dichotomized headway distribution (i.e. there is proportion of vehicles which are retained to follow other vehicles at a minimum headway τ and that the remaining vehicles have headways greater than τ). The equation presented give an estimate of this average delay as a function of the average delay to isolated minor stream vehicles (Adams delay) and the degree of saturation of the minor stream and a form factor (which quantifies the effect of queueing in minor stream).

Heidemann^[12] extended Tanner's mean queue length and mean delay formulas to yield formula for a corresponding distribution. This is achieved by developing a queueing theory approach. The results are subject to the assumption of vehicle arrivals being distributed according the Poisson's law.

Troutbeck^[13] developed equations for the number of vehicles that are stopped when minor stream vehicles arrive at random, with bunched major stream traffic and with the

conventional gap acceptance behaviour. These equations are supported with relationship to predict the proportion of minor stream drivers stopped for a very short period and number of times a driver can be expected to move-up in queue. These measures can be used to predict the fuel consumption and geometric delay at unsignalized intersections.

As we have seen in the above paragraphs, there have been a number of studies regarding priority intersection. But there has been little reported research on the delay characteristics of multiway stop sign intersections.

A more general study of four way stop-sign intersection capacity was studied by Herbert^[14]. He examined the characteristics of the traffic at a limited number of multiway stop-sign intersections and, from these observations, obtained estimates of intersection capacity at multiway stop-sign intersections under a range of traffic distribution assumptions. However, although Herbert's conclusion on intersection capacity are useful, he makes no attempt to specify how the intersection performs in terms of delays experienced in the traffic volume range between zero flow and capacity.

Byrd and Stafford^[15] examined the delays experienced at "unwarranted" four way stop-sign intersection and calculated that care needs to be taken when installing such control to ensure that the magnitude and distribution of delays are acceptable.

Richardson^[16] reported an analytical model of delays

experienced at multiway stop-sign intersection. Delays at multiway stop-sign are shown to be the result of a set of complex interactions between the flows on all approaches to the intersections. Influences on the delays are due to flow on that approach, flow on conflicting approach and flow on opposite approaches. Richardson's model shows good agreement in terms of capacities and level of service for various demand split.

2.3 SIMULATION MODEL

Simulation model on the other hand, attempts to find solution by means of the generated and iterative application of equations and inequalities. Therefore, their applications are extended normally to the complex situations of traffic systems where a large number of variables and constraints play significant role. In recent years, a few traffic simulation models have been developed for intersections which are briefly reviewed in the following paragraphs.

Goode, Pollmar and Wright (1956) formulated a microscopic and deterministic simulation model for signalized intersection. Simulation studies are performed by Benhard (1959) on intersection of two-lane streets with actuated signal control. Lewis^[17] simulated traffic on a four legged, right-angled intersection of high-volume major arterial street with a lower volume minor arterial street to obtain volume warrants at different control strategies. Intersection delays on urban streets

are estimated through simulation by Keel (1962-63). Queueing at uncontrolled T-junction is studied by Aitken (1963). Wright (1968) investigated on stop control delays. Lee and Savur [18] mentioned that results of TEXAS simulation model to a four way stop-sign intersection. They provide one graph relating average delay to total entering volume at intersection. However there are very few details as to how the simulation was conducted, and it appears that their results are in error when compared with the results obtained from other studies. Darzentas (1980) performed simulation of traffic conflicts at T-junctions. With time researches are attempting to develop more efficient models to tackle more and more complex traffic situations. Some of computerised intersection models those relatively new and potentially used for intersection studies (TRB 1981) include: SIGSET(1971), UTCS-15 (1973), SIGCAP (1975), CYCLE (1976), SPLIT (1976), SOAP (1977) and TEXAS (1977).

In following chapters simulation model of freeway merging area, T-intersection and four way stop sign intersection is discussed.

CHAPTER THREE

SIMULATION OF TRAFFIC FLOW

3.1 INTRODUCTION

Computer simulation model can play a major role in the analysis and assessment of the highway techniques, such as demand-supply analysis, capacity analysis, traffic stream models, car following theory, shock wave analysis, and queueing analysis etc. When suitable conceptual model cannot be formulated for the several components of the process and the complexity is due to the stochastic nature of the process and coherent system components and perhaps the presence of multiple alternatives and constraints, computer simulation of the process may be adopted.

A traffic simulation model describes the behavior of traffic stream by considering in detail the behavior of individual vehicles as they move over the specified section of the road. The conduct of traffic experiments on operating facilities has many difficulties. One must find a suitable site, prepare suitable instrumentation set up, and wait for appropriate traffic condition to occur. If the condition lasts only for short time, test may have to be conducted for several days and weeks; at some times, it may not be possible to repeat an experiment in the field. Some traffic situation may not occur at all on the operating facility.

Some experimental runs may be hazardous. Some experiments might require the construction of expensive facilities.

Since the development of highly powerful digital computers, there has been a growing tendency to use digital computer simulation as a method of conducting a variety of experiments, especially those concerning systems having important stochastic features.

3.2 DEFINITIONS OF SIMULATION

"Simulation is defined as a numerical technique for conducting experiments on a digital computer, which may include stochastic characteristics, be microscopic or macroscopic in nature and involve mathematical models that describe the behaviour of a transportation system over extended period of real time."

In more general sense simulation may be defined as a dynamic representation of some part of real world, achieved by building a computer model and moving it through time.

Mize and Cox^[20] proposes that it is a process of conducting experiment on a model of system. Whol and Martin describes simulation as an imitation of real situation by some form of a model that assumes the appearance without reality.

Naylor^[24] suggests that simulation of a system is the operation of a model that is representation of the system, is amenable to manipulations, and from which properties concerning the behavior of actual system can be inferred.

3.3 STEPS IN DEVELOPING A SIMULATION MODEL

There are generally a number of steps in the simulation of a system. Though the details may vary from time to time, number of steps are common to several simulation studies. A flowchart of procedural elements is shown in Fig.3.1. Eleven elements are identified and each is discussed in the following paragraphs.

The first element in the suggested procedure is problem identification. The objective is to state the problem explicitly so that alternative analytical technique can be evaluated in the next procedural element. What are the desired outputs, and what inputs affect the outputs? Constraints of system are also to be considered.

The second element is to investigate that, is simulation the appropriate technique for the problem at hand? Why is simulation a better solution? Can the problem really be solved?

The third element is the formulation of the problem. This is accomplished by developing a first-level flow chart of the model consisting of three connected activities: input, process and output. The input requirements normally include facility design elements, traffic demand patterns, operational rules and/or controls and environmental conditions. The output requirements obviously vary depending on the type of problems but might include such measures of effectiveness as travel time, delay, fuel consumption, accidents, pollution, noise, queue lengths, and stops.

The fourth element is the collection and processing of

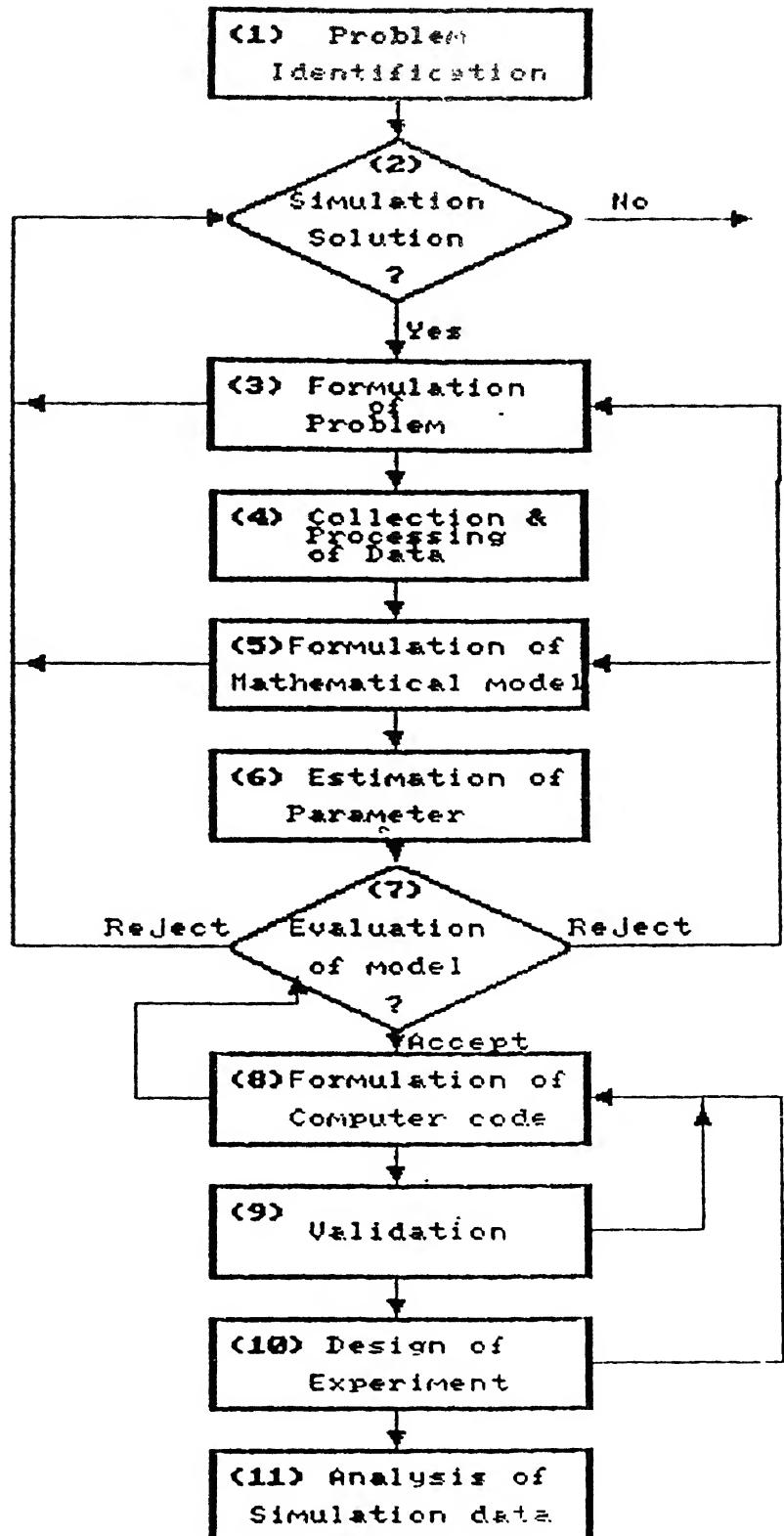


Fig. 3.1 Flow chart of Simulation
Procedural elements^[23]

data based on the previously identified input and output requirements. It is often desirable simply to obscure the traffic system to be studied and initially collect only sample of data. Sample size must be adequate for calibration and validation.

The fifth element is formulation of the mathematical models. This procedure identifies all major subroutines and indicates their connectivity. The steps in each subroutine are identified, described and connected.

The sixth element is the estimation of all required parameters of the model. Parameters of the system are estimated using historical and/or experimental data. Some parameters may be deemed to be deterministic, while others are stochastic.

The seventh element is a manual evaluation of the current state of the model. A decision is made to accept or reject the model. If the model is rejected, reevaluation of the earlier established elements is done and the model is modified accordingly.

The next element is formulation of the computer code. Here an important step is the selection of the computer language and computer facilities. This depends on the one's knowledge of simulation languages and availability of corresponding compilers.

The next element is validation of the model. Generally validation is done on the basis of comparison between the actual recorded output and the output from simulation model for corresponding inputs.

The tenth element is the formulation of the design of simulation experiment. All applications of computer simulation model require a design of simulation experiments, but its comprehensiveness depends on the size and flexibility of the model as well as the complexity and variety of situations to be evaluated.

The last element includes the production runs, analysis of results, and inference.

3.4 SIMULATION OF FREEWAY MERGING AREA

The purpose of this simulation program is to simulate the movement of freeway and ramp vehicles within a freeway merging area (i.e., within the area where an entering or on ramp intersects or merges with the freeway) as shown in Fig 3.2 and to determine the average delay and queue lengths of ramp vehicles entering the freeway. This simulation model also permits the determination of the capacity of entering ramp.

3.5 ASSUMPTIONS MADE IN THE MODEL

1. The merging area is considered to be sufficiently remote from traffic generation sources and traffic controls as to allow both freeway and ramp vehicles to approach the intersection in the random fashion.
2. Freeway vehicles will always be given preference; thus delay is due to ramp vehicles only.
3. Freeway vehicles will not shift lanes within the merging

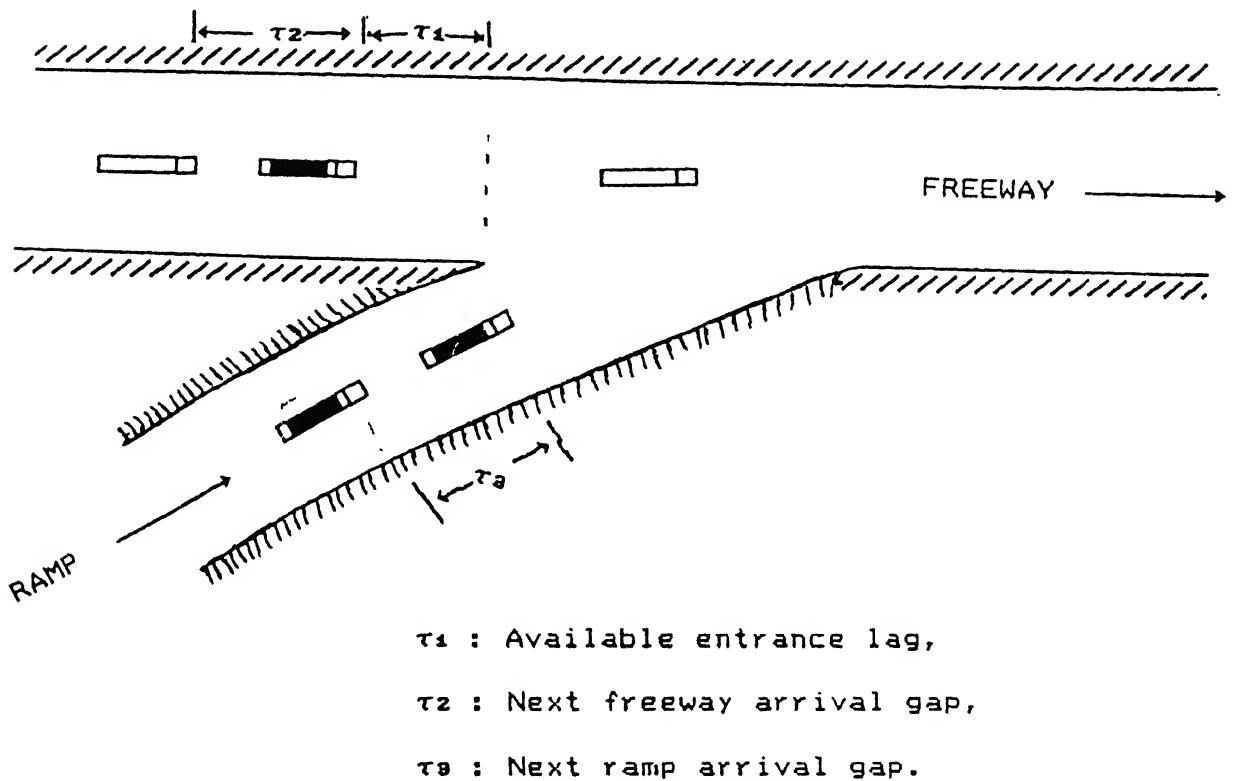


Fig. 3.2 *Freeway merging area (at time T) for simulation program.*

area, and area can be represented by single-lane freeway and ramp.

4. Deceleration rate is assumed to be constant, 2 m/sec^2 , for all vehicles.

5. Operating delay is assumed to be 2 seconds for starting-reaction delay on starting to enter the major road.

6. Overtaking is not permitted on any road near intersection.

7. No pedestrian traffic exists.

8. Intersection is on level terrain.

3.6 INPUTS TO THE MODEL

1. Total simulation time.

2. Minimum headway gap between two vehicles.

3. Traffic volume for calculating the next arrival gap.

4. Distribution of acceptable entrance gap length to ramp vehicles.

5. Free speed of vehicle approaching intersection, for calculating delay caused by deceleration of vehicles on slow down at intersection.

6. Vehicle length for different types of vehicles. The various types of vehicle considered are scooter/motor cycle, tempo, mini bus, bus, car/jeep/van, LCV, and trucks.

3.7 FORMULATION OF MODEL

The simulation of freeway merging area is done in following fashion. Once ramp vehicle reaches the intersection, the driver scans the traffic on major road. As major road vehicle is

having priority over minor road vehicles so the driver of minor road vehicle bases his decision on whether or not to enter the freeway on his expected arrival time at nose of the ramp and on the availability of an acceptable freeway gap. If at his arrival at the intersection there is an acceptable gap, he will enter, if not, he will be delayed and must wait for a later gap. Model can be divided into following procedure:

Procedure vehicle arrival

Procedure gap acceptance

procedure queue_length

Main program

3.8 VEHICLE ARRIVAL PROCEDURE

In India heterogeneity in traffic conditions is a common phenomenon. On a road, vehicles like truck, buses, cars, two wheelers, bicycles, rickshaw, and animal drawn vehicles move in both directions. Speeds, identification numbers, vehicle types, arrival rates are the main parameters of interest. Arrival rates are differing from time to time. Different types of vehicle used in this model is listed in Table 3.1.

Now for the arrival of vehicles we have to generate the vehicle arrival gaps and hence the headway distribution. Cowan^[10] discussed the use of four headway models: viz. the exponential distribution, the shifted exponential distribution, and two dichotomies exponential distribution. In our model we have chosen

Table 3.1 Details of vehicles used in model

I.D. NO.	VEHICLE TYPE	VEHICLE LENGTH	MEAN SPEED IN M/SEC.	STANDARD DEVIATION
1	MINIBUS	4.5 m	14.0	1.2
2	TRUCK	8.0 m	11.1	1.8
3	CAR/JEEP	2.5 m	15.0	1.0
4	TEMPO	3.0 m	8.50	1.6
5	SC/MC	1.2 m	9.00	1.3
6	BUS	8.0 m	11.1	1.8
7	CYCLE	1.3 m	05.4	1.4
8	LCV	5.0 m	11.0	1.7
9	TRACTOR	7.5 m	8.00	1.9

Cowan's M2 model which is based on the principle that there is always a minimum headway of τ between two successive vehicles.

The cumulative headway distribution is given by:

$$P(t) = 1 - e^{-\lambda(t-\tau)} \quad \text{for } t \geq \tau \\ = 0 \quad \text{otherwise} \quad \dots \dots \text{Eqn.3.1}$$

where

t is headway between two successive vehicles.

τ is minimum headway gap.

λ is decay constant expressed by

$$\lambda = 1/q - \tau$$

where q is arrival rate and equal to V/T

V is number of vehicle passing during total simulation time T

Using Monte Carlo technique, Eqn.3.1 can be transformed to express the gap length as function of probability function P. On transposing and taking log (to base e) of both sides, eqn. is:

$$t = \tau - \left(\frac{T}{V} - \tau \right) * \ln(1-p) \quad \dots \dots \text{Eqn. 3.2}$$

If random fraction is generated and substituted for p, the arrival gap length t can be computed directly by using Eqn. 3.2. So arrival time vehicle = arrival time of previous vehicle + t.

3.10 GAP ACCEPTANCE PROCEDURE

Once a minor road vehicle reaches the intersection, it stops, and the driver scans the traffic on major road. The waiting driver has criteria for selecting a suitable gap in the traffic for his merging maneuver. Table 3.2 gives the information on the percentage of ramp vehicles that faced and accepted freeway gaps within various ranges. This table is a result of a study conducted at the Yale Bureau of Highway Traffic.

Table 3.2 *Gap acceptance table*

RANGE (i)	RANGE OF GAPS FACED BY RAMP VEHICLE (sec)	MID VALUE OF EACH RANGE GAP[i];	% OF MINOR ROAD VEH FACING & ACCEPTING GAPS IN RANGE i
1.	0.5 - 1.4	GAP[1]=1.0	ACCEPT[1]= 0.0
2.	1.5 - 2.4	GAP[2]=2.0	ACCEPT[2]= 50.0
3.	2.5 - 3.4	GAP[3]=3.0	ACCEPT[3]= 85.0
4.	3.5 - 4.4	GAP[4]=4.0	ACCEPT[4]=100.0

Flow chart for gap acceptance routine in freeway merging simulation program is given in Fig.3.3

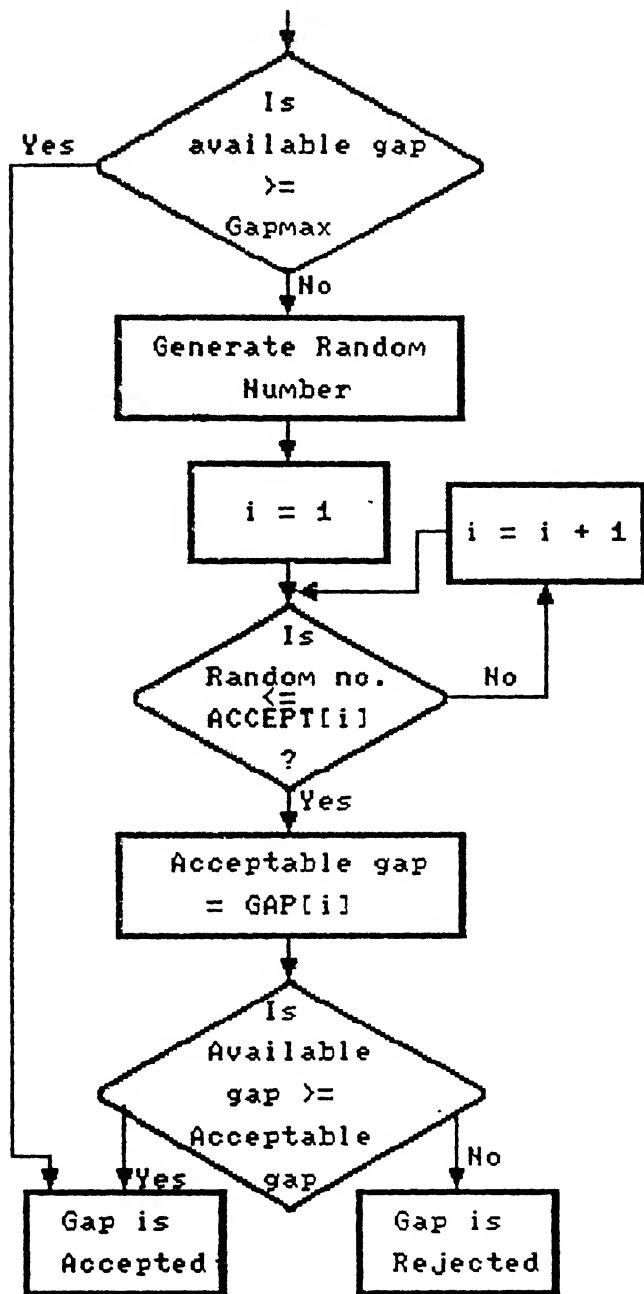
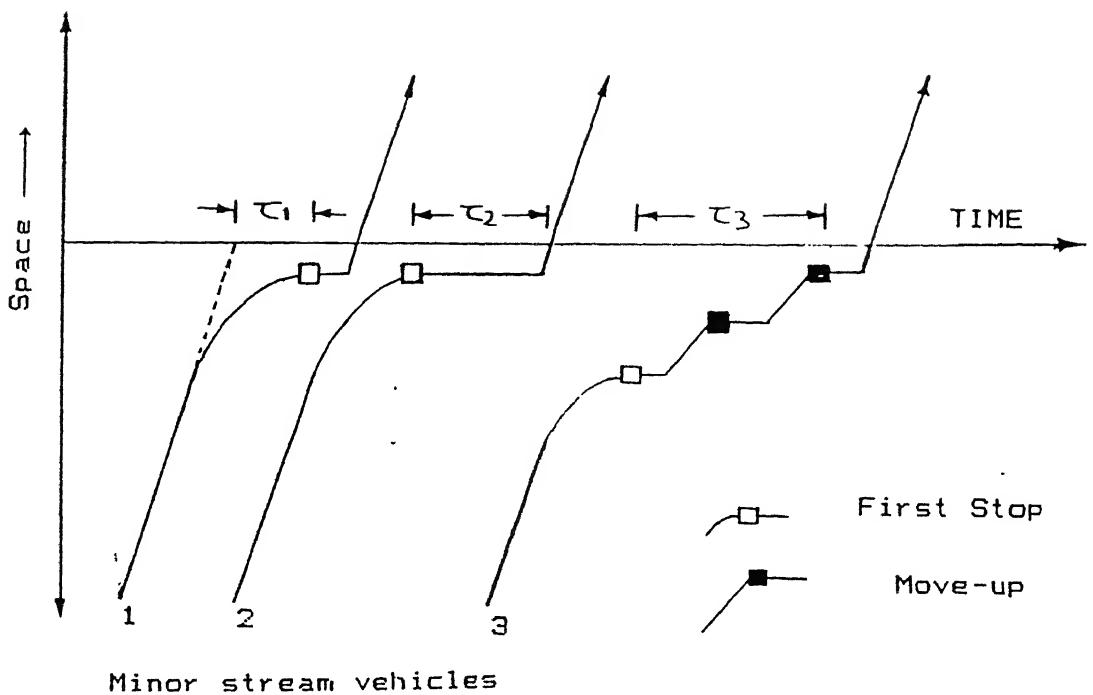


Fig. 3.3 Flow chart for Gap acceptance routine^[22]

A random number is generated and compared successively with Accept[1], Accept[2], Accept[3], until it is found that random is equal to or less than that acceptance percentage for one of the ranges; the mid value (GAP[i]) of the range corresponding to this acceptance percentage becomes the acceptable gap. The available gap is then compared to the acceptable gap. If the available gap is equal to or greater than the acceptable gap then it is accepted otherwise rejected.

3.11 PROCEDURE QUEUE LENGTH

A vehicle on minor road cannot enter the freeway till there is no vehicle waiting in the queue. This happens when arrival of a vehicle is earlier than the departure of previous vehicle. So the arrival time of vehicle at top of queue will be equal to the departure time of previous vehicle plus some starting time plus time taken to move the distance of one vehicle length. As vehicles move to the head of queue, it is assumed that they will move-up one by one after the previous vehicle has found an acceptable gap in freeway. Each minor stream vehicle stops at each move-up so there will be some operating delay every time. This concept of move-ups is explained in Fig.3.4. The number of move-ups for a particular vehicle will be equal to number of vehicles waiting in the queue in front of it. This can be found by scanning the linked list of vehicles. The length of the queue can also be found by summing all vehicle lengths and distance headway



τ_1 = Deceleration delay

τ_2 = Looking-for-gap delay

τ_3 = Queuing delay

- 1 → Vehicle comes at intersection & finds suitable gap and merges. No queue at intersection.
- 2 → Vehicle comes at intersection and gap available is not acceptable, so vehicle is waiting for suitable gap in mainstream. That is looking-for-gap delay.
- 3 → Vehicle finds queue at intersection, move-ups stops in queue.

Fig. 3.4 Concept of move-ups of side street vehicle approaching intersection.

between each vehicle. Assuming a constant speed at each move-up, queue delay can be found by dividing queue length by average speed. Queue delay is defined as time taken by vehicle from reaching last position of queue to head of queue or at nose of intersection. A flow chart for procedure queue_length is shown in Fig.3.5.

3.12 MAIN PROCEDURE

The general nature of the model can be best explained by flow chart given in Fig. 3.6. The flow chart depicts pictorially the sequence in which instructions are carried out in the model.

Programming languages used in this model is PASCAL. Data structures like Arrays, Records, Linked lists and Pointers are used to improve the efficiency of the model. For generating the random numbers in built library function of NAG and C are used.

Program was run on HP-9000 system.

3.13 OUTPUT OF THE MODEL

The major factor in the study of simulation model of ramp intersection is delay to minor road vehicle. Delay to a vehicle is sum of three components of delay which are deceleration delay, queueing delay, and looking for gap (lfg) delay. All of these components of delay have already been described in previous sections of this chapter and it can be best understood by Fig. 3.4. A graph shown in Fig. 3.7 is plotted between average delay to ramp vehicle (in seconds) versus ramp volume (number of vehicles/

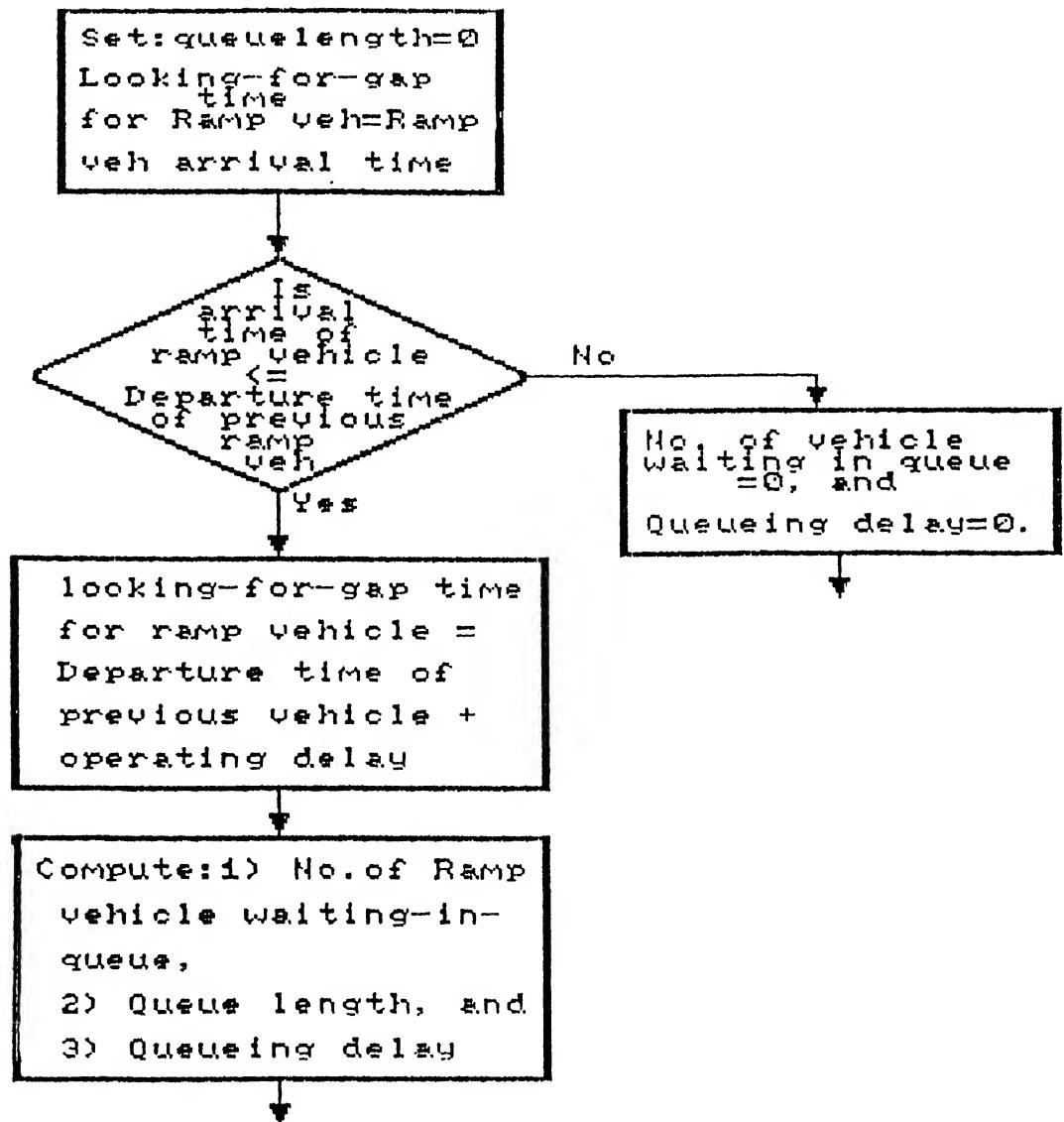


Fig. 3.5 Flow chart for procedure queue_length.

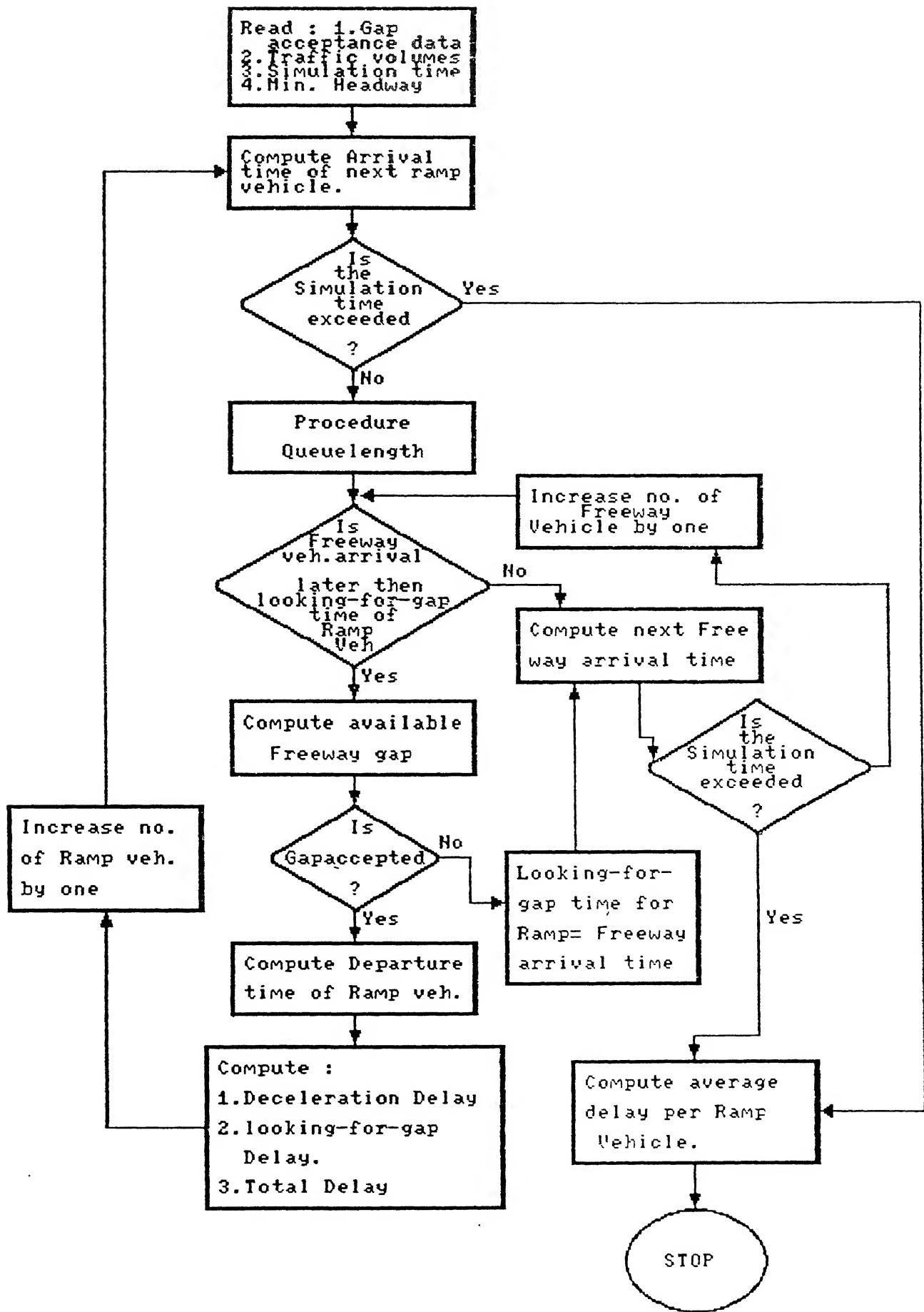


Fig. 3.6 Flow chart for freeway merging simulation.

hour) for fixed freeway traffic volume. From Fig. 3.7 it is seen that for a fixed major road flow the delay increases with increase in ramp volume but after increase in the ramp volume beyond certain flow rate of increase of delay increases rapidly. So the

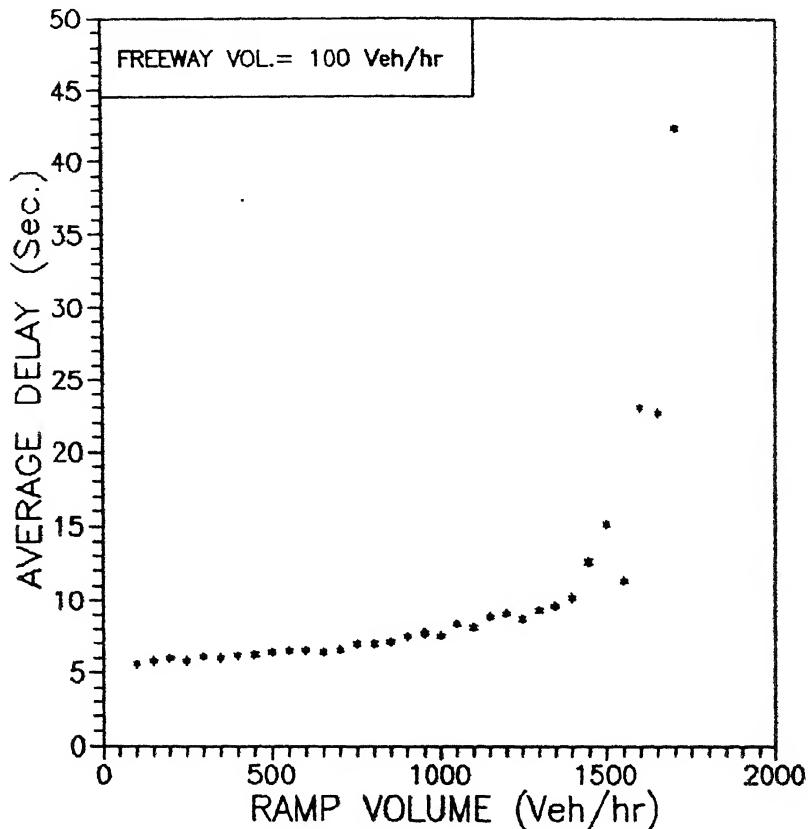


Fig. 3.7

flow for which delay is very high is called capacity of intersection. In Fig. 3.8, curves are drawn for different freeway volume, It is seen that by increasing freeway volume delay increases.

From the Fig.3.9, which is drown between ramp volume and different average delay (deceleration delay, queueing delay, lfg

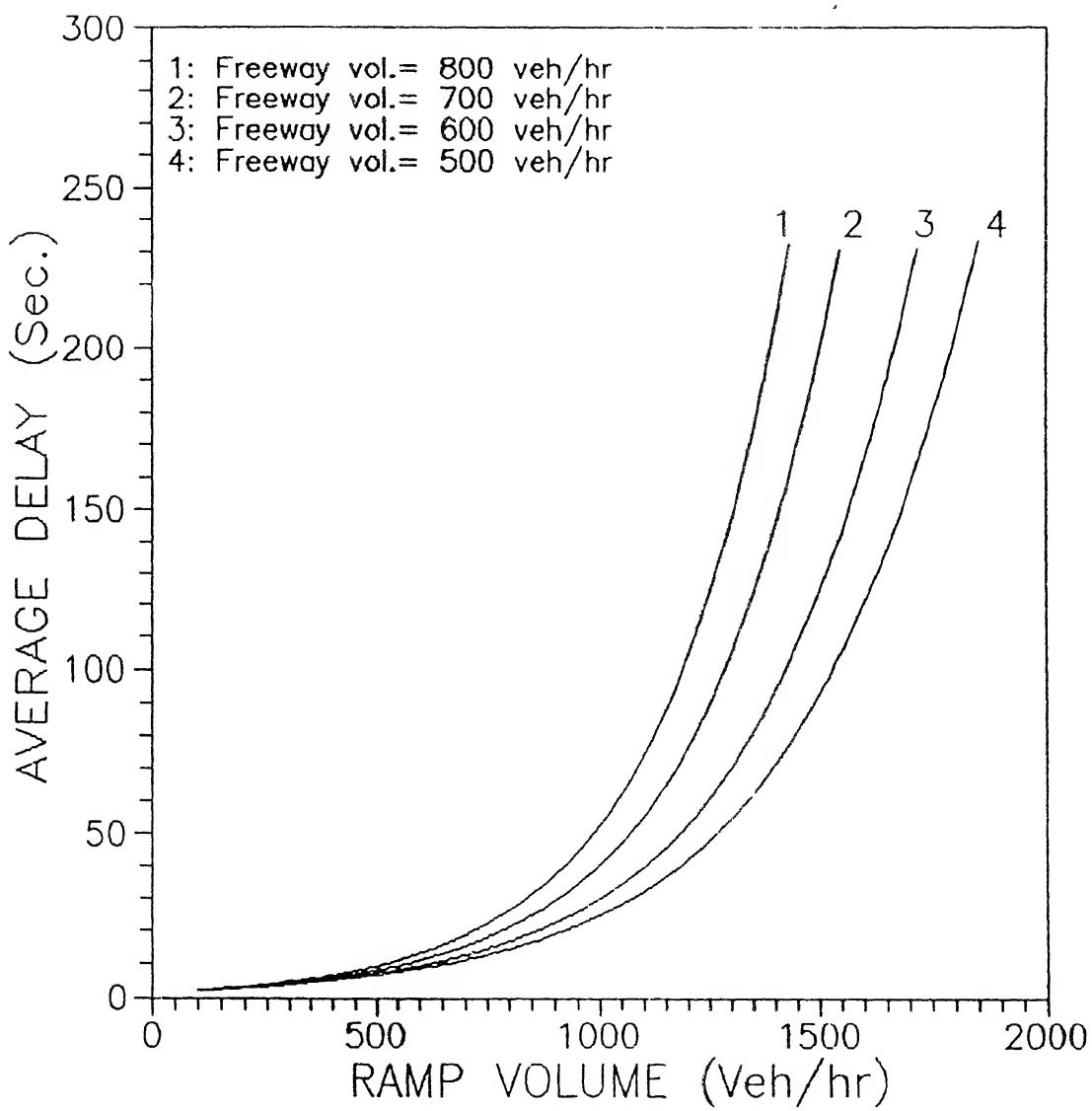


FIGURE 3.8

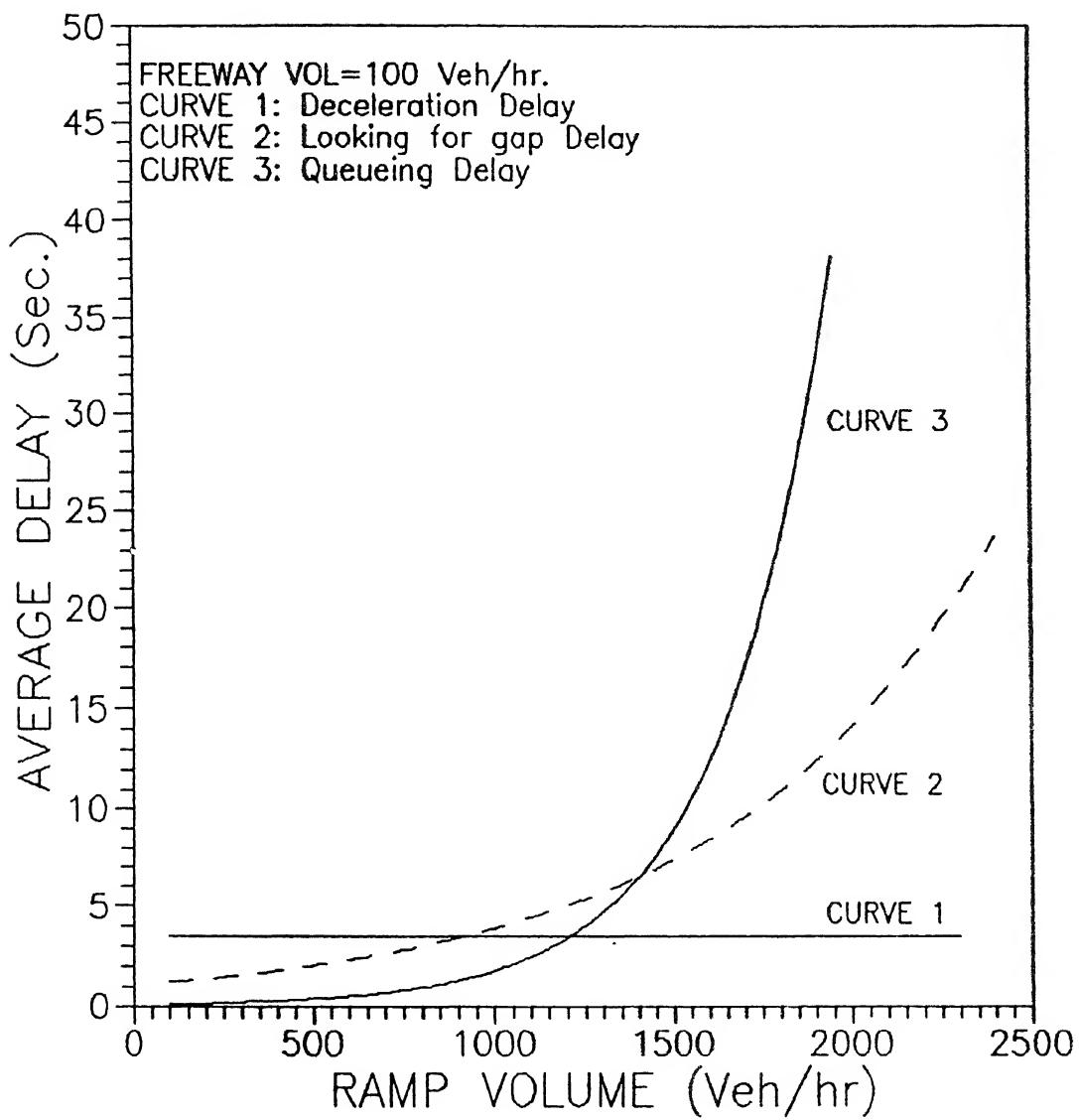


FIGURE 3.9

delay), it is seen that initially when ramp volume is low the major part of total delay is due to lfg delay but after increasing the ramp volume we see that rate of increase of queueing delay is more than rate of increase in lfg delay. In this model it is assumed that speed of all vehicle approaching intersection is constant so here deceleration delay is constant for all traffic flow. Curve shown in fig. 3.9 is exponentially distributed.

In next chapter simulation model for T intersection and four way stop sign intersection is discussed.

CHAPTER FOUR

SIMULATION MODEL USED TO DETERMINE THE PERFORMANCE OF UNSIGNALIZED INTERSECTION

4.1 GENERAL

Performance of an intersection is greatly influenced by its type, driver's behaviour, traffic composition, and capacity of the intersection. In this chapter simulation model is used to determine the performance of T-intersection and four way stop-sign intersection. The main difference between the above two intersections is that the former is priority intersection and the later is uncontrolled intersection. First simulation model of T-intersection is explained and the model for four way intersection in the sequel.

4.2 SIMULATION MODEL FOR T-INTERSECTION

The main aim of this model is to simulate all traffic approaching, passing through and leaving a controlled unsignalised priority intersection. The model deals with a minor road traffic intersecting a major two way road traffic with stop sign control. That is the traffic approaching the intersection on the major road has the right of way, while those on the minor road must stop and look for gaps before they join the major traffic stream.

4.2.1 MODEL ASSUMPTIONS

Assumptions made in preparation this model are more or less same as given in section 3.5 of previous chapter, with major differences as:

1. The major road is a two lane two way whereas the minor road is single lane, and
2. Stop sign exists only on the minor road and the both lanes of the major road have priority.
3. It is assumed that gap acceptance criteria for both the left and right turning vehicle is the same.

4.2.2 MODEL INPUTS

Inputs to the simulation model of the T-intersection is the same as listed in section 3.6 of previous chapter.

4.2.3 MODEL FORMULATION

Major difference in the formulation of the T-intersection model and freeway intersection model is that in the case of T-intersection a side street vehicle can take turn either to the left or right. So side street vehicles face different problems while turning to the left or right. While deciding to make a left turn, side street vehicle scans traffic of only one lane, that is nearside lane of the major road but right turning vehicles have to scan the traffic on both the lanes, nearside and farther lanes of the major road. So looking for gap delay for left turning vehicle is lesser than right turning vehicle. Average delay to left and right turning vehicles, delay for each delayed

vehicle, maximum queue length and number of vehicles in the queue are then determined from the operational path of the model to determine the performance of T-intersection. The model can be divided into the following parts:

```
Procedure Vehicle arrival  
procedure gap acceptance  
procedure queue_length  
main .program.
```

First three procedures namely vehicle arrival, gap acceptance, and queue length, have already been described in the previous chapter in section 3.8, 3.9, 3.10 respectively.

4.2.4 MAIN PROGRAM

The general nature of the model can be best understood in more precise manner with the help of the flow charts given in Fig 4.1.

Referring to Fig 4.1 which depicts the activities of the vehicle crossing the stop-sign T-intersection, the various steps involved are given below:

```
step 0- Initialise and set clock time = 0;  
step 1- Compute arrival time of vehicles approaching from the minor road and major road.  
step 2- If arrival time of minor road vehicle is earlier than the departure time of the previous minor road vehicle then
```

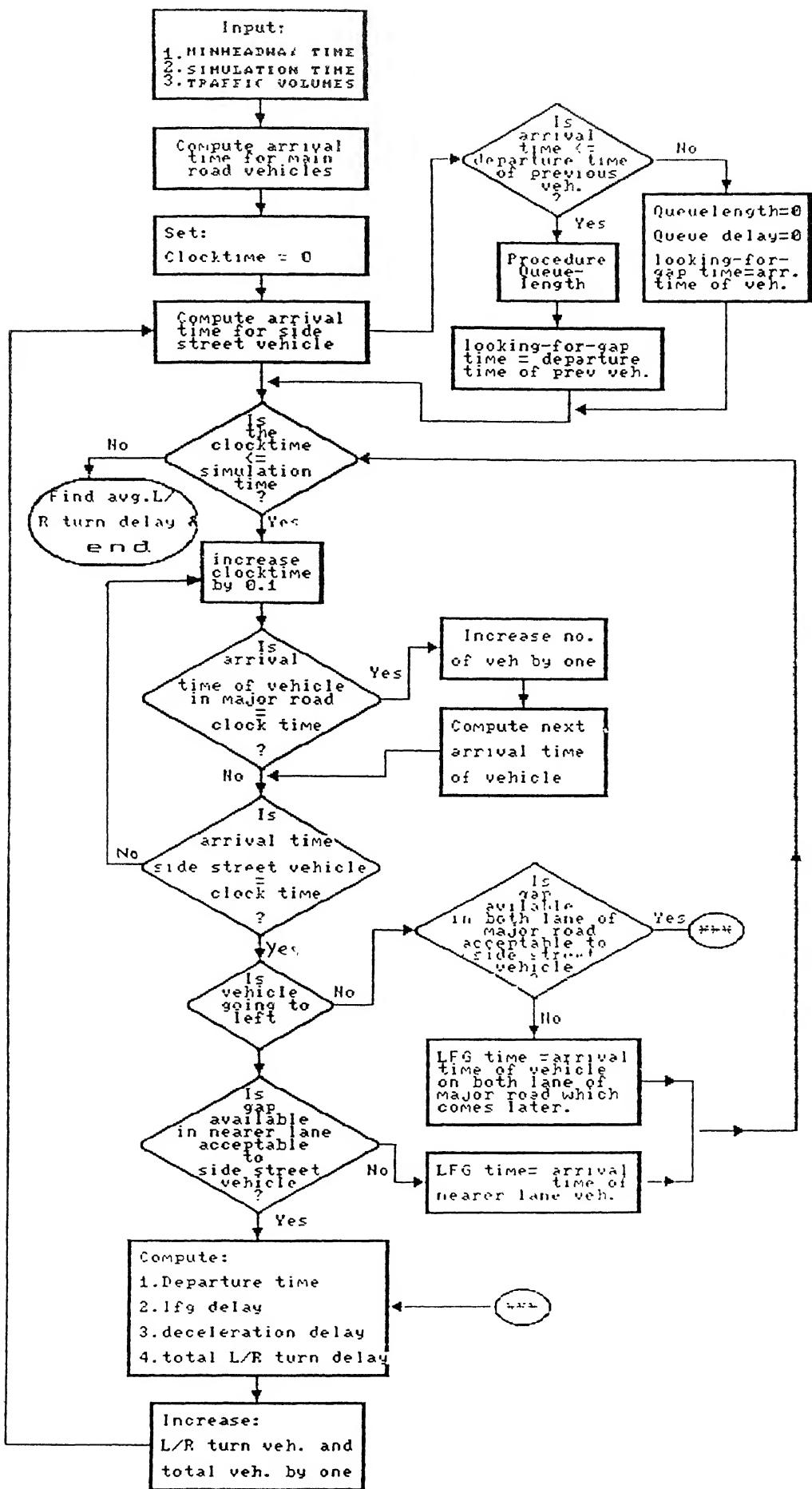


Fig. 4.1 Flow chart for simulation model of T-intersection

determine the number of vehicles waiting in the queue, queue length both number as well as spaces (add all vehicle's length in queue and some minimum headway between each vehicle) and queueing delay, and looking for gap time for that vehicle will be equal to the departure time of previous vehicle plus operating delay. If not then looking for gap time for side street vehicle will be equal to arrival time of that vehicle, and the queue length and queuing delay will be zero.

step 3- Is the clock time less than simulation time, if yes then then increase clock time by 0.1 second else go to step 11.

step 4- Is arrival time of vehicle, either from nearside lane or farther lane, is equal to clock time then increase the number of vehicles by one and compute the next arrival time of major road vehicle.

step 5- If arrival time of side street vehicle is equal to clock time, and then if vehicle is taking left turn then go to step 6 otherwise go to step 7.

step 6- If gap available in nearside lane is accepted to left turning vehicle then go to step 9 else the looking for gap time of side street vehicle is the equal to the arrival time of the vehicle in the nearside lane and go to step 3.

step 7- For right turn vehicle, if the gap available by both nearside and farther lane is accepted to side street vehicle then go to step 9 otherwise looking-for-gap time for side street vehicle is set equal to the arrival time of vehicles of the two

lane major road which comes later and go to step 3.

step 8- Departure time of side street vehicle = looking for gap time of side street vehicle + operating delay.

Deceleration delay of vehicle = vehicle's free speed $/(2 * dc)$

where dc = deceleration constant = 2 m/sec^2 (all vehicle types)

Looking for gap (Lfg) delay = departure time - arrival time.

Total delay = Lfg delay + deceleration delay + queueing delay.

step 9- Increase respective left/right turn vehicles by one and also increase side street vehicle by one. Go to step 1.

step 10- Find the average left turn delay, average right turn delay and average total delay.

step 11- Stop.

4.3 SIMULATION MODEL FOR FOUR WAY STOP-SIGN INTERSECTION

Simulation model of four way stop-sign intersection is totally different from the earlier two models, because the earlier model of T-intersection and freeway merging were based on priority of the right of way to the major road vehicle. But in this model, which is a uncontrolled type of intersection, earlier arriving vehicle of any approach has priority and if vehicles of different lanes arrive simultaneously then priority is given to the vehicle on the right.

4.3.1 MODEL ASSUMPTIONS

Apart from the previous model assumptions additional requirements are given as:

1. Intersection consists of two major roads of equal priority, each having two streams.
2. Headway between vehicles on one lane road is independent of headway in other lanes.
3. Minimum headway time is constant for all vehicles.
4. Stop sign exists on all approaches.
5. All the vehicles are first in line when they arrive at the intersection.

4.3.2 MODEL INPUTS

Inputs to the simulation model is the same as given in the previous model and only the additional feature is that each approach is assigned (as input data) probabilities that vehicle will turn (left or right) or continue straight through.

4.3.3 FORMULATION OF MODEL

Simulation model for four way stop-sign intersection is formulated by the following procedures:

Vehicle arrival procedure

Procedure queue length

Procedure initialisation

Procedure turn

Procedure collision

Procedure find delay

procedure Veh_arrival

main program.

First two procedure namely, vehicle arrival and queue length is similar to the earlier model. Rest of the procedures of the model are described in the following section.

4.3.4 PROCEDURE INITIALISATION

Initialisation is done to start with the first vehicle and for the vehicle which finds an empty queue:

Total queue length = 0

Queuing delay to vehicle = 0

No of vehicles waiting in line = 0

looking-for-gap time for vehicle = arrival time of vehicle.

4.3.5 PROCEDURE TURN

From input data we know the probabilities of vehicles taking turn or going straight. If x is the probability of left turn, and y is probability of right turn then the procedure turn is shown in Fig. 4.2:

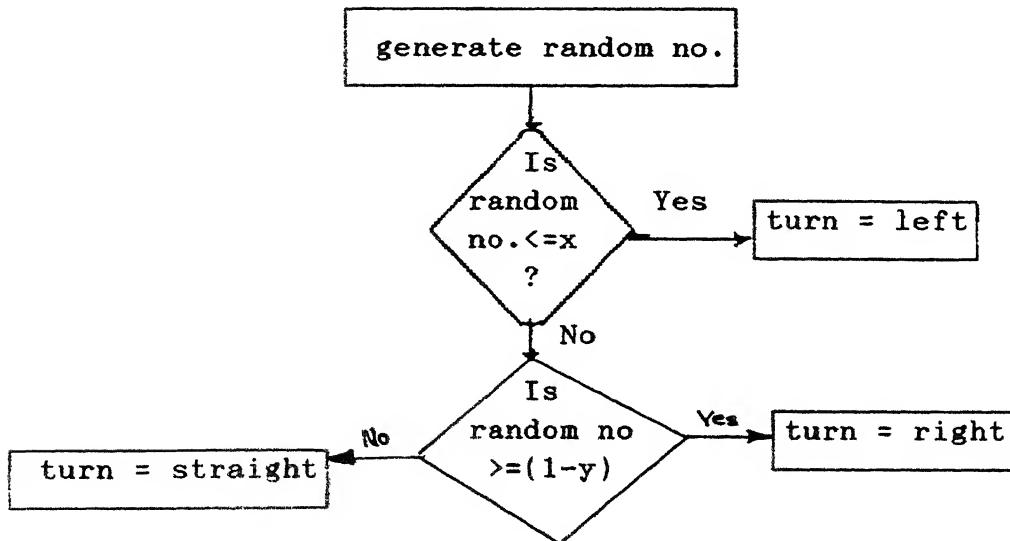


Fig. 4.2 Flow chart for procedure turn

4.3.6 PROCEDURE COLLISION

When vehicles from different approach lanes arrive simultaneously at the intersection or vehicle taking different movements meet in between intersection conflicts do occur. To avoid conflicts driver's judgment of crossing is most important. So conflict points in four way uncontrolled intersection plays an important role in deciding the performance of these intersection. A typical four legged cross roads is shown in Fig.4.2 with one lane each at entry and exit on the approaches and the points where vehicle collision and conflict occur. The various types of conflict at intersection are:

Crossing conflict

Merging conflicts

Diverging conflicts

On a right angled road intersection with two way traffic the total number of conflicts are 24. This consists of 16 crossing conflicts, which are of major conflicts point. The merging and diverging conflicts are considered as minor conflicts, numbering from each in this case as shown in Fig 4.3.

So in the simulation model one has to consider all these aspects of conflict avoidance by vehicles. For example if a vehicle coming from northern side taking left turn then a vehicle coming from western side going straight and vehicle from southern side taking right turn which is departed few seconds before the

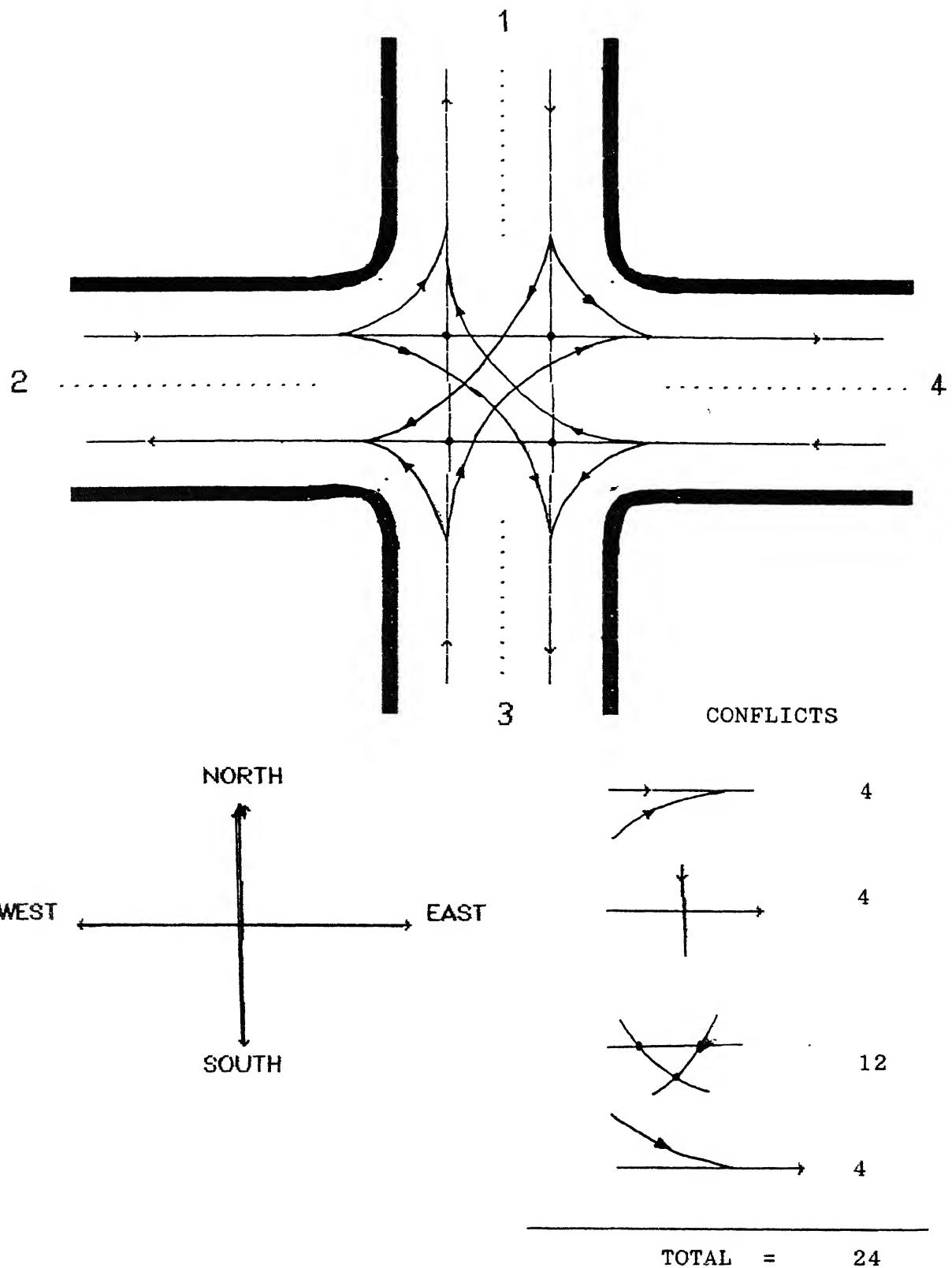


Fig. 4.3 Conflicts with two way traffic

arrival of northern side vehicle may conflict at point 1 as shown in Fig. 4.3. So vehicle from northern lane will only enter to the intersection when there is no conflict with earlier departed vehicles from other approaches.

A flow chart showing all possibilities of collision is shown in Fig. 4.4. this flow chart allows us to decide whether a vehicle is going to have a conflict if yes then find the time after which there is no collision. Flow chart given is a particular case of a vehicle approaching intersection from northern side.

4.3.7 PROCEDURE FIND_DELAY

In the procedure `find_delay` the departure time of vehicle is found and all delay components are calculated.

Departure time = looking-for-gap time + operating delay

Deceleration delay = Free speed of vehicle/(2* decen const.)

looking-for-gap delay = departure time - vehicle arrival time

total delay = deceleration delay + queueing delay + lfg delay

A flow chart for procedure `find_delay` is shown in Fig. 4.5

4.3.8 PROCEDURE VEHICLE_ARRIVAL

Procedure `vehicle arrival` is an important component of the simulation model for four way stop-sign intersection. In this model, vehicle which comes first departs first with no conflicts in intersection and priority is given to the right side vehicle if both vehicle arrives simultaneously. For this a flow chart is

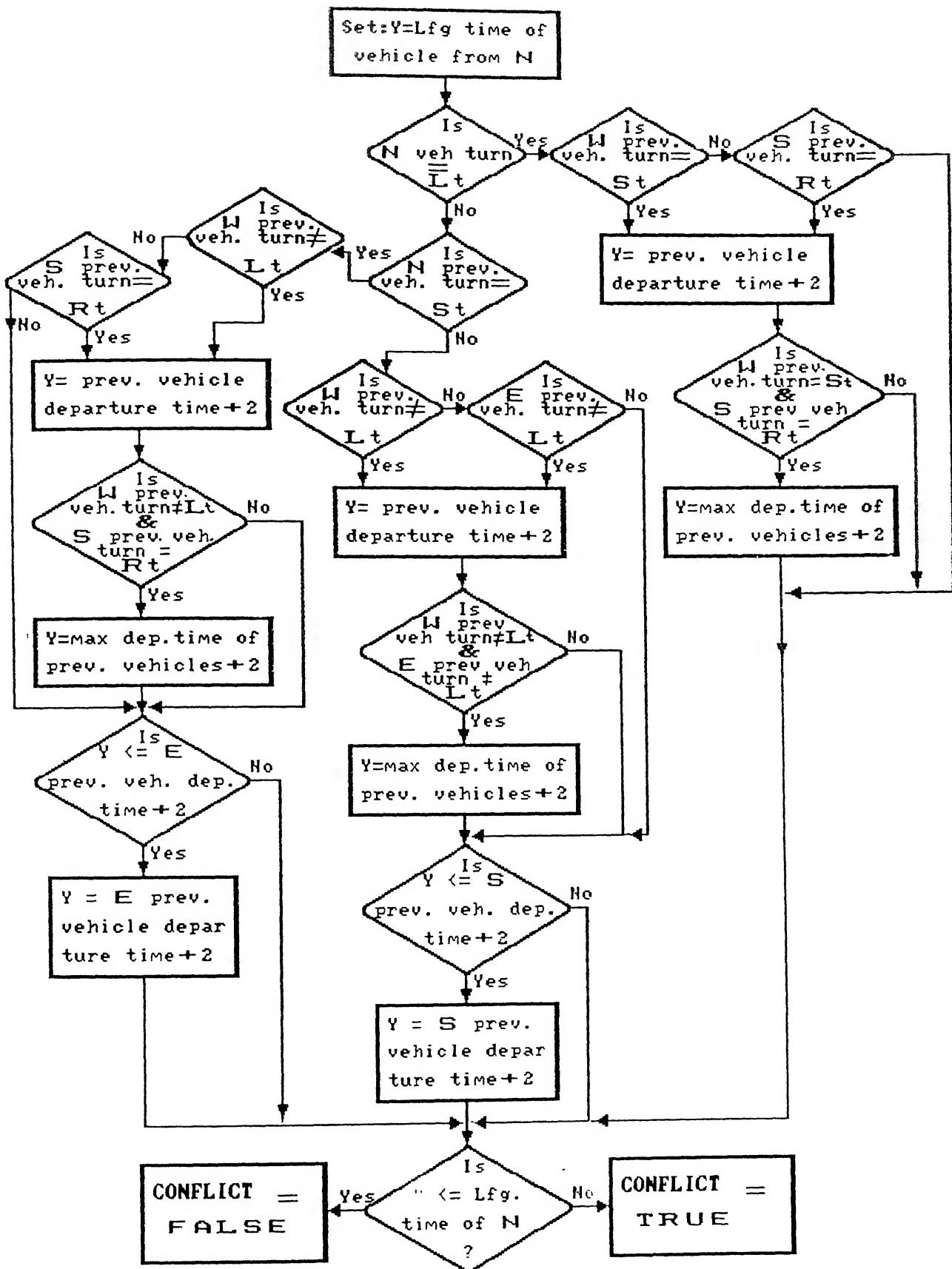


Fig. 4.4 Flow chart for Procedure Collision

given in Fig. 4.6.

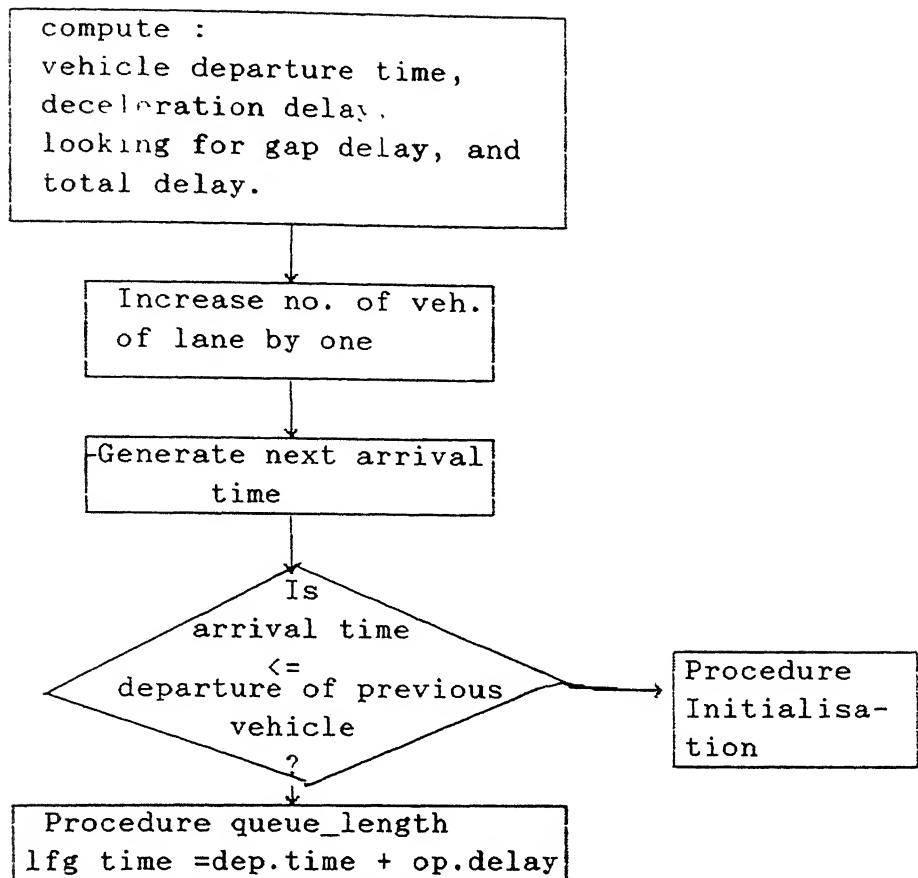


Fig. 4.5 Flow chart for Procedure `find_delay`

4.3.9 MAIN PROGRAM

In main program using all above procedures, vehicles generated and moved on all approaches of the road till the end of simulation time and then the average delay to each approach vehicle is determined and the average delay of intersection is also found. A flow chart for main program is shown in Fig 4.7.

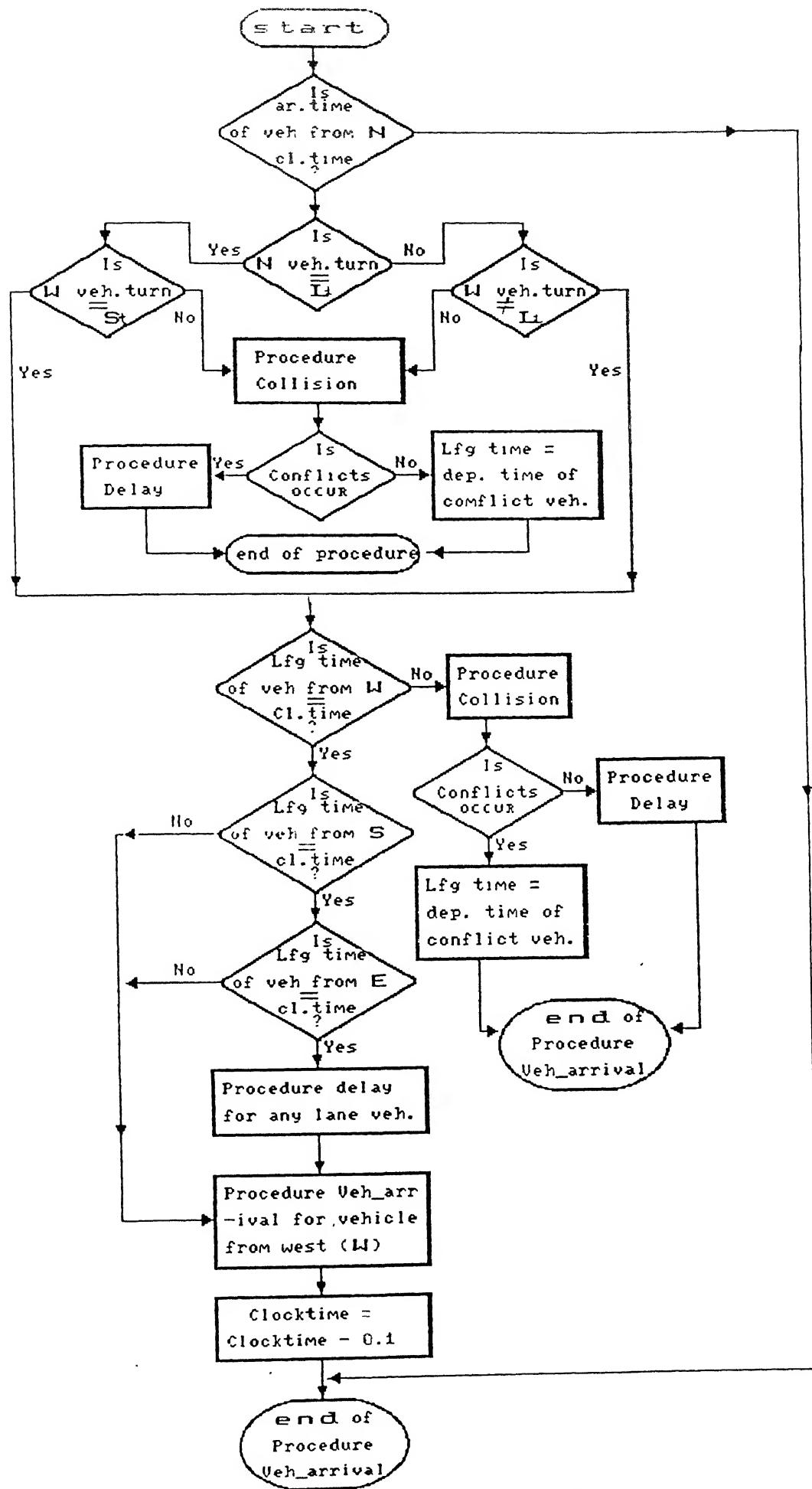


Fig. 4.6 Flow chart for Procedure Veh_arrival

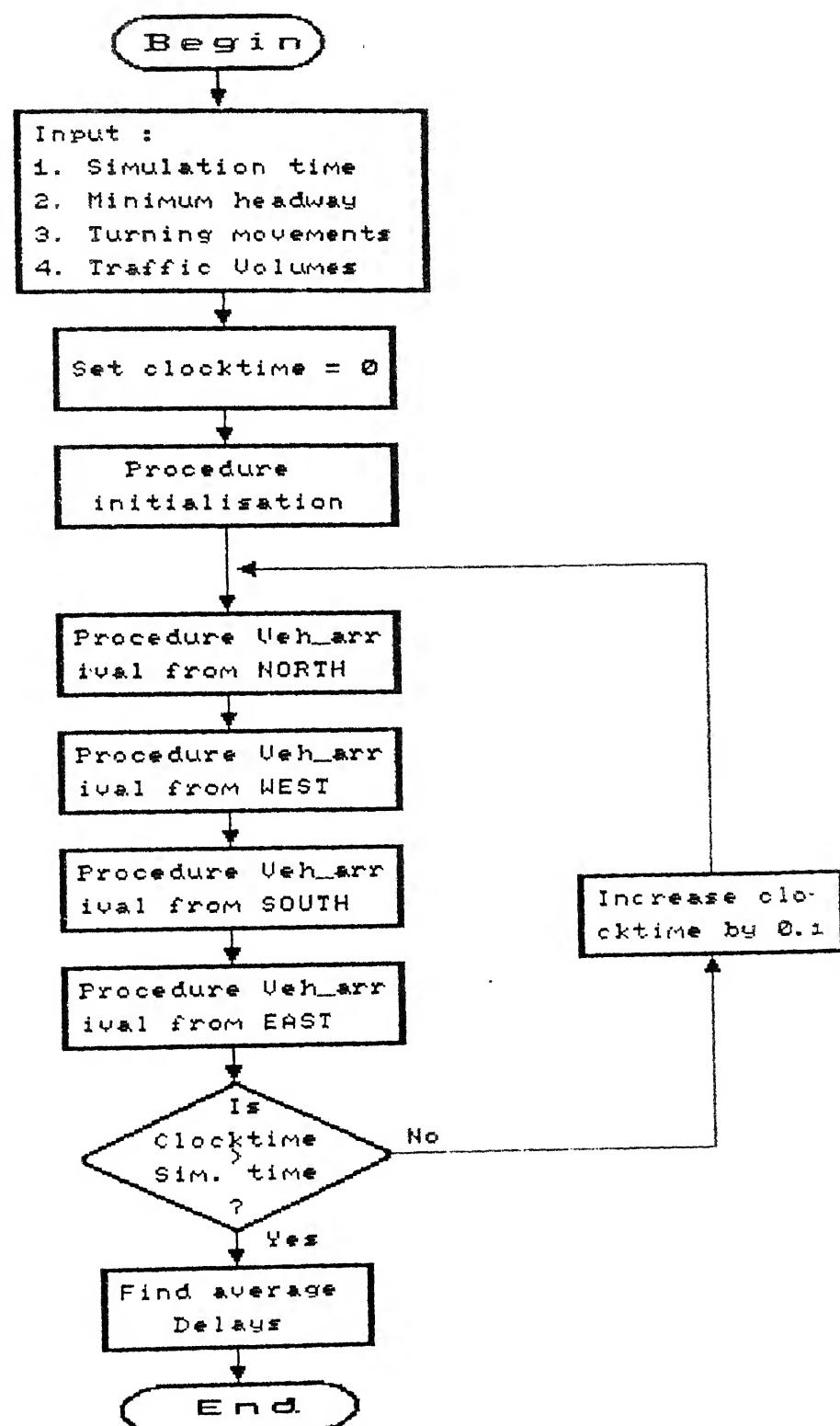


Fig. 4.7 Flow chart of main program of four way
stop sign intersection

CHAPTER FIVE

VALIDATION OF THE SIMULATION MODEL

5.1 INTRODUCTION

Formulation of a model involves the definition of a structure and a set of parameters. Validation involves the verification that the structure is correct and the parameter estimates are reasonable. Generally validation of the model is based on the agreement between the output of the model and available information from real life situations if they exist. The closer such an agreement better is the validity of model. The model can be used to simulate future conditions only after it has been validated and found to be a replicate the dynamics of the process observed in the real word system under study. Validation is done to judge the correctness of the model and the various sub models that are involved in framing the model. Sub models like desired speed distribution, gap acceptance probabilities, etc. that are based on the observed data must be validated separately. Using the overall simulation results, it is necessary to calibrate the values of some of the parameters and decision logics. The overall validation of the simulation model is a test of how well the sub models have been assembled into a realistic structure of the system.

5.2 MEASURES OF EFFECTIVENESS FOR VALIDATION

Parameters to be used as measures of effectiveness in validation should be such that they represent the output of the whole system and can also be accurately measured in the field. These properties should be such that significant disagreement implies that the model is unsatisfactory. We therefore decided to concentrate on analysis of the difference between the observed and simulated means and standard deviations in order to quantify just how good or bad the comparison were. The parameter adopted for the model validation in this model is different type of vehicle arrival rate, different types of vehicle and overall average delay to vehicle. Some other parameter (e.g. waiting time of individual vehicles) might be adopted but due to certain limitations it was not possible to do so.

5.3 TRAFFIC INPUTS FOR VALIDATION

It was desirable to first validate the traffic simulation model alone with observed traffic data on the selected road intersection. Number of data collection stations depends on type of intersection on selected road intersection are identified and collection of the following data for each vehicle passing the intersection is done.

1. Vehicle type
2. Direction of travel
3. Time of arrival and departure at intersection

and departure pattern of vehicle on intersection by manually. One can record the whole activity of intersection on video recorder system. But due to time limit and other resources limitations it was not possible to do so.

In this case we have validated the model in other way, as we can have an approximate observation of average delay to vehicles on an intersection. So by knowing the traffic volumes of each approach and traffic movements in each direction we can find average delay to vehicle by simulation model and can compare to observed average delay.

5.6 TRAFFIC DATA COLLECTION

Traffic data collection was done on Kalyanpur T intersection, where a two lane major road (G.T.Road) meets an one lane minor road (Panki Road). Traffic movements are in all directions. Data were collected both in the morning and evening peak period on working days. Due to above limitations only following data at Kalyanpur intersection was collected:

- i) Vehicle arrival rate,
- ii) Types of vehicle,
- iii) Vehicular turning movements.

Number of vehicles crossing the intersection is noted for each 5 minute interval and then traffic volumes (in PCU) was calculated. Traffic data collected at Kalyanpur intersection for evening peak hour for all approaches is given in table 5.1, 5.2 &

**DISTRIBUTION OF VEHICLES COMING FROM PANKI SIDE AT
KALYANPUR INTERSECTION**

EVENING PEAK HOUR													6.00 PM TO 7.00 PM				
TIME	0	1	2	3	4	5	6	7	8	9	10	11	12	13			
0-5	L	4	0	1	0	0	0	0	0	5	20	0	2	22			
	R	16	0	0	1	0	1	0	0	18	22	0	2	24			
5-10	L	6	0	0	0	0	1	0	0	7	15	1	0	16			
	R	2	0	0	0	0	0	0	0	2	11	1	1	13			
10-15	L	2	0	0	0	0	0	0	0	2	23	0	2	25			
	R	5	0	0	0	0	0	0	1	6	18	0	1	19			
15-20	L	1	0	0	0	0	3	0	0	4	10	0	2	12			
	R	8	1	0	0	0	0	0	1	10	8	0	0	8			
20-25	L	3	0	0	0	0	0	1	0	4	12	0	1	13			
	R	6	0	0	0	0	1	0	1	8	8	1	1	10			
25-30	L	1	0	0	0	0	1	0	0	2	12	0	0	12			
	R	7	0	1	0	0	1	0	0	9	11	0	1	12			
30-35	L	2	0	0	0	0	0	0	0	2	10	0	0	10			
	R	6	0	1	0	0	0	0	0	7	12	0	1	13			
35-40	L	5	0	1	0	0	0	0	0	6	6	1	0	7			
	R	7	0	0	0	0	3	0	0	10	12	0	0	12			
40-45	L	3	0	1	0	0	0	0	0	4	22	0	0	22			
	R	4	0	1	0	0	0	0	0	5	16	1	0	14			
45-50	L	2	0	1	0	0	0	1	0	4	18	1	1	21			
	R	6	0	0	0	1	2	0	1	10	7	2	1	8			
50-55	L	7	0	1	0	0	1	0	0	9	9	0	0	9			
	R	10	0	0	0	0	1	0	0	11	14	0	0	14			
55-60	L	3	0	8	0	0	0	0	0	1	12	24	0	0	24		
	R	6	0	1	0	0	0	0	0	2	7	12	1	1	14		
TOTAL	122	1	17	1	1	15	2	5	164	329	8	17	354				
LEFT TURN VOL.	83	1	4	1	1	9	0	4	103	148	4	9	161				
* LEFT TURN	68	100	23.5	100	100	60	0	80	62.8	45	50	52.9	45.5				
VOLUME IN PCU'S	61	1	17	1	1	15	2	5	103	109	8	17	134				
LEFT TURN VOL. IN PCU'S	41	1	4	1	1	9	0	4	61	49	4	9	62				
TOTAL VOLUME IN PCU'S	= 237																

TOTAL LEFT TURN VOLUME IN PCU'S = 123

PERCENTAGE LEFT TURN VOLUME = 51.9

0-Turn, 1-Scooter/Motorcycle, 2-Tempo, 3-Truck, 4-Bus. 5-Minibus,
6-Car/Jeep/ Van, 7-LCV, 8-Tractor, 9-Total Fast Vehicle, 10-Cycle,
11-Tonga & others 12-Rickshaw, 13-Total Slow Vehicle.

**DISTRIBUTION OF VEHICLES COMING FROM I.I.T. SIDE
AT KALYANPUR INTERSECTION**

EVENING PEAK HOUR

TIME	0	1	2	3	4	5	6	7	8	9	10	11	12	13
	S	17	5	1	1	2	3	0	0	29	39	1	1	41
0-5	R	6	0	0	0	0	0	0	0	6	8	0	0	8
	S	12	9	4	0	1	4	3	0	33	20	1	1	22
5-10	R	4	0	1	0	0	1	0	0	6	13	2	1	16
	S	15	11	1	2	3	1	2	0	35	21	1	0	22
10-15	R	12	0	0	0	0	1	0	1	14	10	0	0	10
	S	6	5	2	2	2	1	0	1	19	21	1	1	23
15-20	R	6	0	0	0	0	3	0	0	9	6	1	0	7
	S	10	5	4	2	1	4	0	1	27	15	0	1	16
20-25	R	4	0	0	0	0	0	0	0	4	8	0	1	9
	S	12	7	2	1	1	5	0	1	29	28	1	1	30
25-30	R	3	0	0	0	0	0	0	0	3	9	0	0	9
	S	9	11	4	2	0	1	1	0	28	27	3	1	31
30-35	R	3	0	0	0	0	1	0	0	4	12	2	0	14
	S	14	7	4	6	0	4	1	3	39	20	1	0	21
35-40	R	2	0	1	0	0	0	0	0	3	9	0	0	9
	S	7	7	3	2	1	5	2	1	28	11	3	0	14
40-45	R	6	0	0	0	0	0	1	0	7	17	0	0	17
	S	13	11	10	1	1	6	2	0	44	11	0	0	11
45-50	R	2	0	0	0	0	1	0	0	3	13	0	0	13
	S	16	9	8	3	1	4	0	0	41	21	0	1	22
50-55	R	7	1	0	0	0	0	0	0	8	7	2	0	9
	S	12	8	4	3	0	4	0	0	31	20	3	3	26
55-60	R	4	0	2	0	0	0	0	1	7	9	1	0	10
	TOTAL	202	96	51	25	13	49	12	9	457	375	23	12	410
RIGHT TURN VOL.	59	1	4	0	0	7	1	2	74	121	8	2	131	
% RIGHT TURN	29.2	1	7.8	0	0	14.3	8.3	22.2	16.2	32.3	34.8	16.7	32	
VOL. IN PCU'S	101	96	51	25	13	49	12	9	356	125	23	12	160	
RIGHT TURN VOL. IN PCU'S	29	1	4	0	0	7	1	2	44	40	8	2	50	

TOTAL VOLUME IN PCU'S = 516

TOTAL RIGHT TURN VOLUME IN PCU'S = 94

PERCENTAGE RIGHT TURN VOLUME = 18.2

0-Turn, 1-Scooter/Motorcycle, 2-Tempo, 3-Truck, 4-Bus, 5-Minibus,

6-Car/Jeep/Van, 7-LCV, 8-Vactor, 9-Total Fast Vehicle, 10-Cycle,

11-Tonga & others, 12-Rickshaw, 13-Total Slow Vehicle.

TABLE 5.2

**DISTRIBUTION OF VEHICLES COMING FROM CITY SIDE
AT KALYANPUR INTERSECTION**

TIME	PEAK HOUR	6.00 PM TO 7.00 PM												
		0	1	2	3	4	5	6	7	8	9	10	11	12
	S	10	5	2	1	1	5	0	0	24	14	0	2	16
0-5	L	2	0	0	0	0	1	0	1	4	12	0	2	14
5-10	S	14	8	4	0	2	4	0	0	32	16	0	1	17
	L	5	0	0	0	0	0	0	0	5	12	0	0	12
10-15	S	21	5	3	1	1	4	0	0	35	12	0	2	14
	L	4	0	0	0	0	1	0	0	5	16	2	2	20
15-20	S	15	5	3	1	1	1	2	0	30	14	0	1	15
	L	7	0	0	0	0	0	0	1	8	10	0	3	13
20-25	S	16	1	1	3	1	2	1	0	25	15	0	4	19
	L	3	0	0	0	0	1	0	0	4	7	0	3	10
25-30	S	16	7	4	1	2	4	0	0	34	9	0	3	12
	L	11	0	0	0	0	2	0	0	13	7	0	3	10
30-35	S	16	6	3	0	1	3	1	0	36	18	1	1	20
	L	6	0	1	0	0	1	0	0	8	12	0	2	14
35-40	S	8	9	0	2	1	4	0	1	25	10	0	0	10
	L	9	0	0	0	0	0	0	0	9	10	0	2	12
40-45	S	13	7	7	2	1	2	0	0	32	21	1	0	22
	L	3	0	0	1	0	1	0	0	5	13	0	2	15
45-50	S	14	12	2	0	2	2	0	0	32	13	0	0	13
	L	3	0	0	1	0	1	0	0	5	15	0	3	18
50-55	S	14	8	1	0	1	4	0	1	29	11	1	0	12
	L	3	0	0	0	0	1	0	0	4	18	0	1	19
55-60	S	18	8	3	0	2	3	0	0	34	18	0	0	18
	L	3	0	0	0	0	0	0	0	3	10	0	2	12
TOTAL		234	81	34	13	16	49	4	4	435	313	5	39	357
LEFT TURN VOL.		59	0	1	2	0	9	0	2	73	142	2	25	169
* LEFT TURN		25.2	0	2.9	15.4	0	18.4	0	50	16.8	45.4	40	64.1	47.3
VOL. IN PCU'S		117	81	34	13	16	49	4	4	418	104	5	39	148
LEFT TURN VOL. IN PCU'S		29	0	1	2	0	9	0	2	43	47	2	25	74

TOTAL VOLUME IN PCU'S = 466

TOTAL LEFT TURN VOLUME IN PCU'S = 117

PERCENTAGE LEFT TURN VOLUME = 25.1

0-Turn, 1-Scooter/Motorcycle, 2-Tempo, 3-Truck, 4-Bus, 5-Minibus,

6-Car/Jeep/Van, 7-LCV, 8-Tractor, 9-Total Fast Vehicle, 10-Cycle,

11-Tonga & others, 12-Rickshaw, 13-Total Slow Vehicle.

5.3. Data of traffic volumes and turning movements for other three intersections (Hanuman Mandir T-junction, Kidwainagar crossing, Site No. 1 crossing) is taken from the report of NATPAC for Kanpur city.

5.7 DISTRIBUTION OF DIFFERENT MODES

Traffic distributions characteristics at the intersection are analysed for the Kalyanpur intersections which is simulated for validation. The idea is only to study these characteristics to have an idea of the traffic flow behaviour. A mode wise distribution of traffic at intersection for evening peak hour is shown in Fig. 5.1. As we see from Fig. 5.1 that major proportion of vehicles in stream is bicycle which consist of 45 % of total traffic.

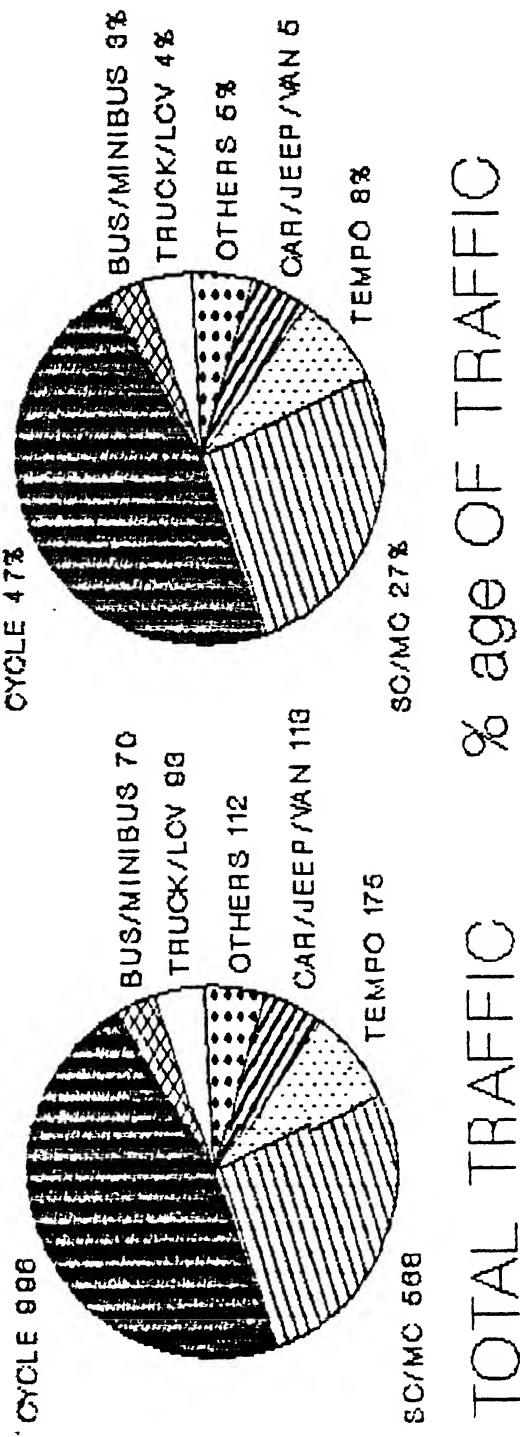
5.8 ANALYSIS OF DATA

Some of the assumptions made in model is different from the field observations. Assumptions like no overtaking at intersection, movement of vehicles in one lane discipline queue, no pedestrian movement are violated in the field observations. Due to heterogeneity in traffic flow, and movements of more than one vehicle per lane at a time, traffic volumes of some vehicle like scooter/motorcycle and bicycle is expressed in PCU (passenger car unit) per lane per hour, while determining total traffic volume. PCU values for scooter and motor cycle is considered same as recommended by IRC but for the case of bicycle we have taken PCU

MODEWISE DISTRIBUTION OF TRAFFIC AT KALYANPUR T-INTERSECTION

EVENING PEAK HOUR

6.00 PM TO 7.00 PM



OTHERS - TONGA, RICKSHAW & HQ/AC

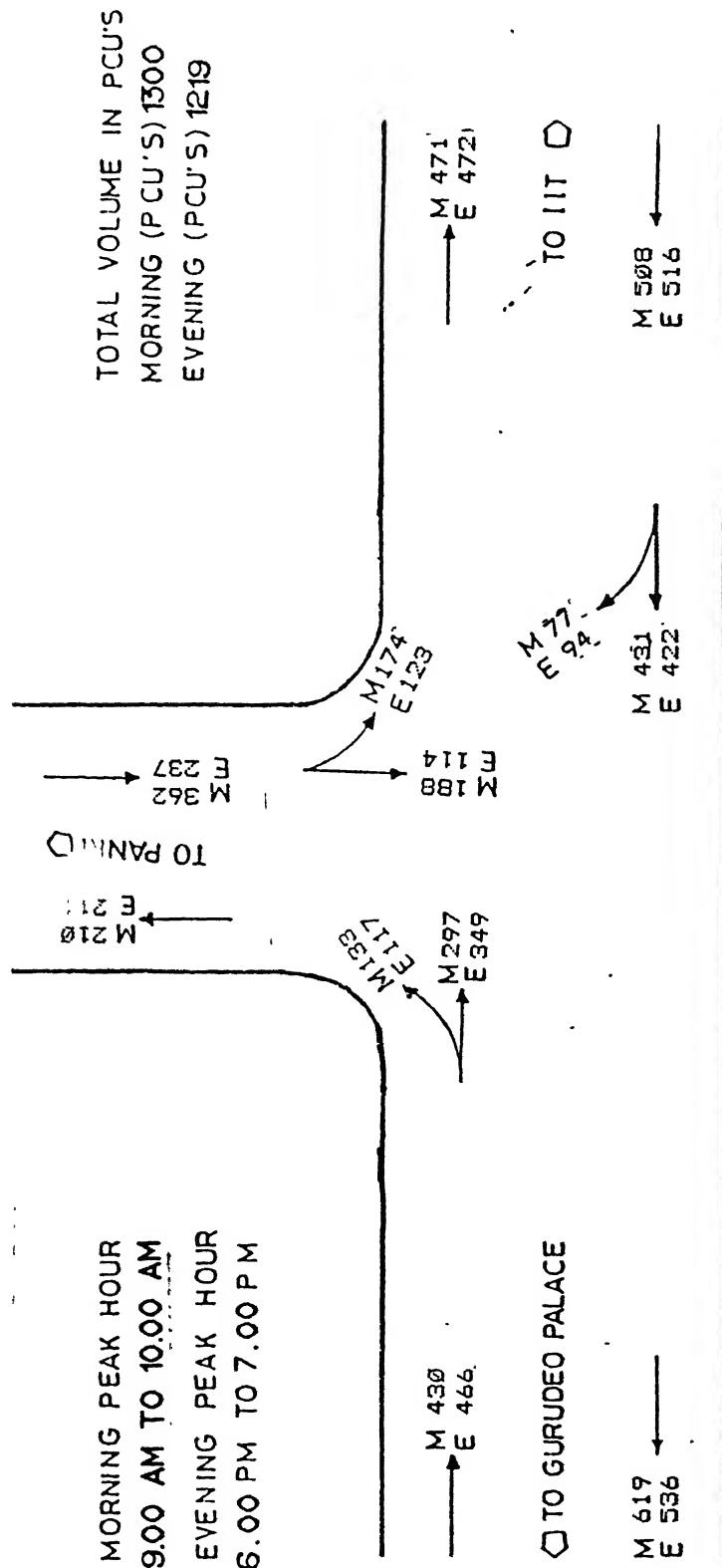
FIGURE 5.1

value of 0.25 instead of 0.5. It was observed that about 3 to 5 bicycles are passing in the lane simultaneously at the intersection. An average of 4 bicycles is considered as one passenger car in further evaluation of delay. Thus assumption of PCU value of 0.25 for bicycle is quite reasonable.

Peak hour traffic flow distribution in PCUs at different intersections is shown in Fig. 5.2 to 5.5. Contrary to the assumption of delay to only minor vehicles in the simulation model for priority intersection, it was observed that traffic at all approaches was delayed. It is also observed that there are no priority intersections in the region under consideration. So the model cannot be validated for priority intersection. The four way intersection model was validated for the following types of intersection:

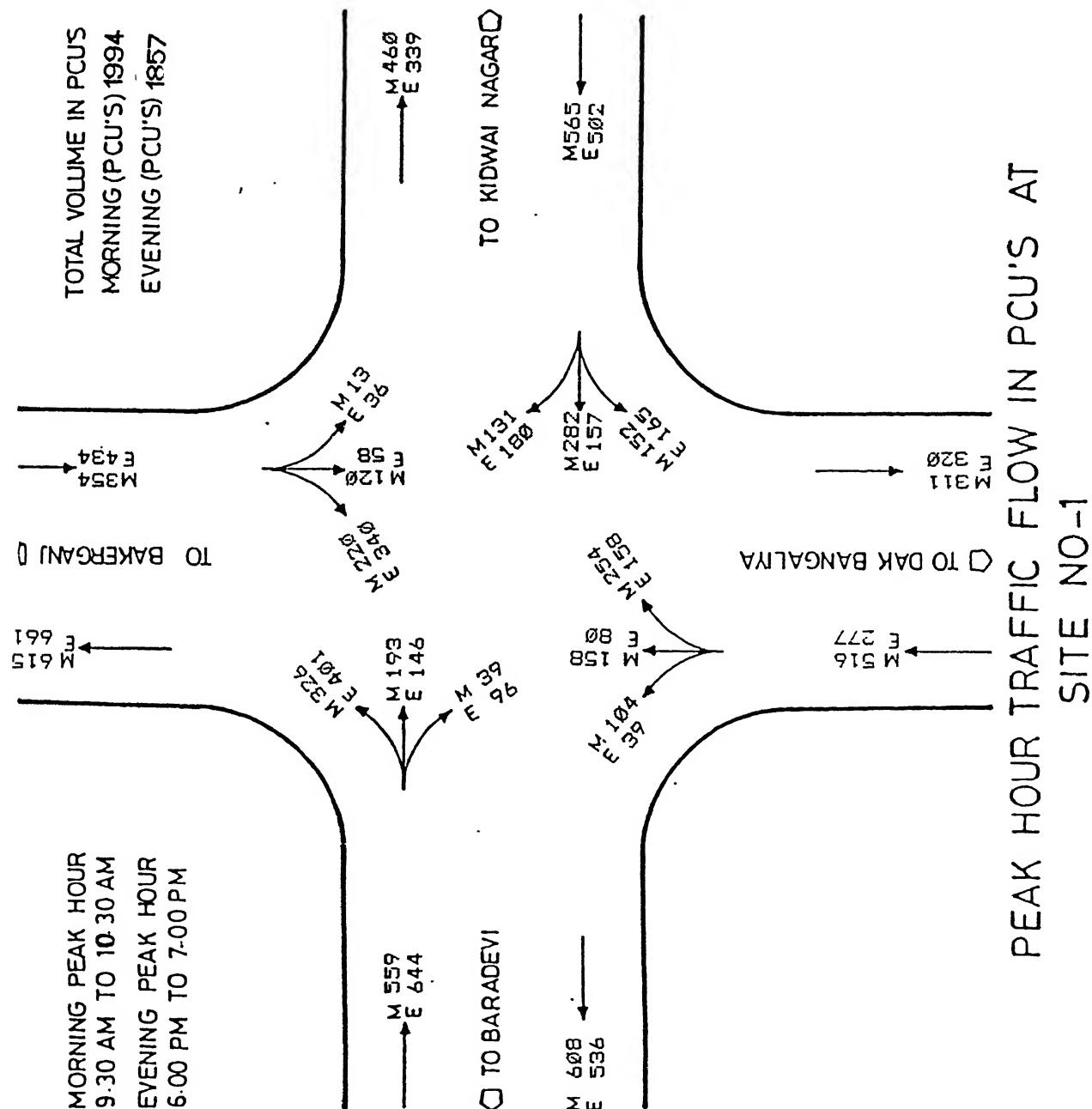
1. Kidwainagar Crossing (four way intersection)
2. Site No.1 Crossing (four way intersection) near Kidwainagar
3. Kalyanpur intersection (T-intersection)
4. Hanuman Mandir T-junction

Validation of simulation model of four way intersection for Kalyanpur and Hanuman Mandir T-junctions are done by giving traffic volume of one lane as zero and turning movements of another lane towards zero volume lane equal to zero. Further it is assumed that pedestrian movement at intersection do not have any effect on delay of vehicles.



PEAK HOUR TRAFFIC FLOW IN PCU'S AT
 KALYANPUR JUNCTION

FIGURE 5.2



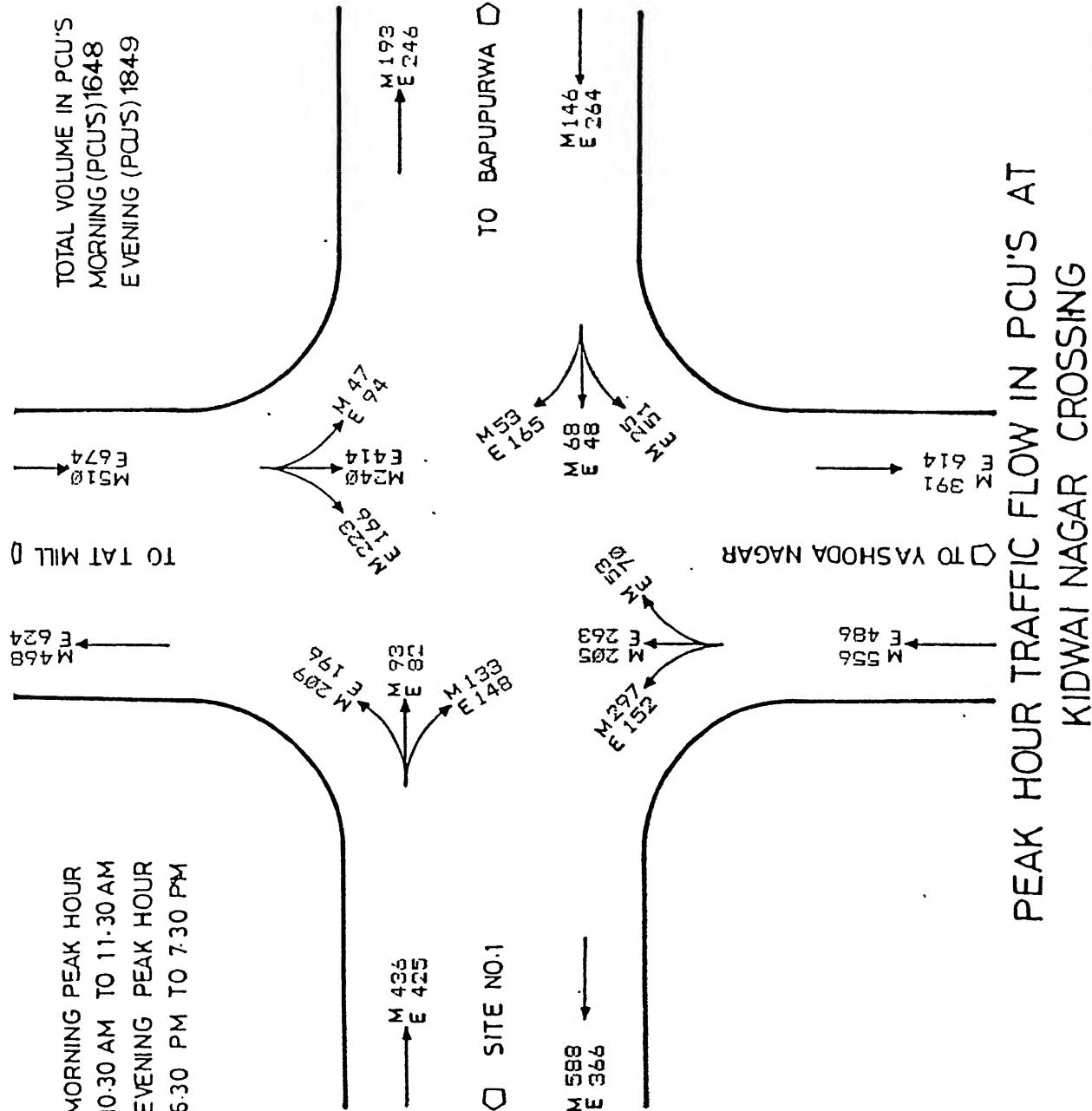
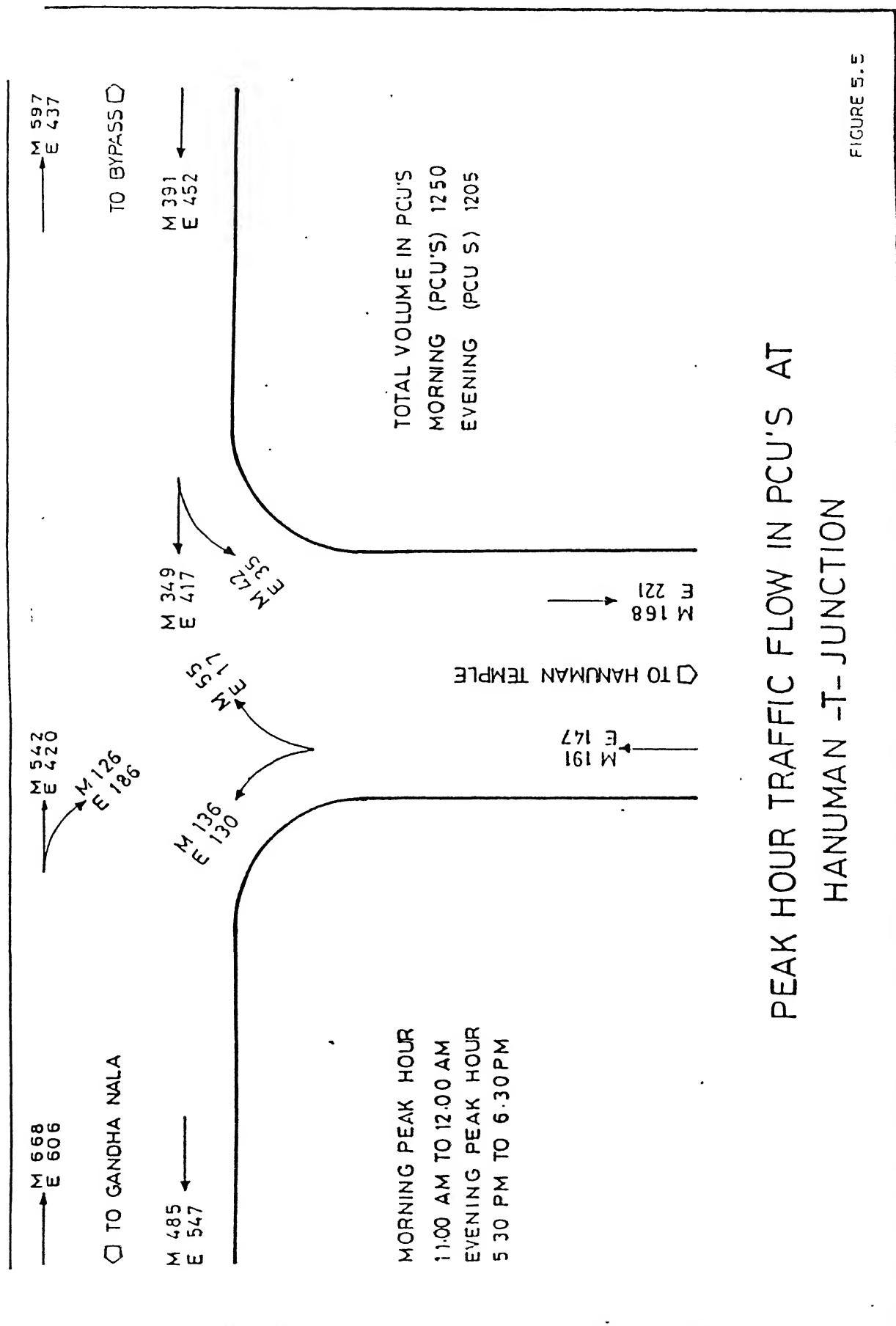


FIGURE 5.4



5.9 COMPARISON OF SIMULATED AND OBSERVED DELAY

Data available for all the four intersection is simulated and analysed. Average delay for a vehicle per lane for Kalyanpur intersection in the morning peak is found to be 10.49 seconds and for evening peak it is 9.56 seconds. Simulation model results in terms of traffic delay to a vehicle is presented in Table 5.4.

Table 5.4 Average Delay At various intersections from simulation model

Sr. No.	Intersections	M / E	Intersection Volume	Average Delay(Sec.)
1.	Kalyanpur intersection	M	1300 veh/hr	10.49
		E	1219 veh/hr	9.56
2.	Hanuman Mandir T-junction	M	1250 veh/hr	9.14
		E	1206 veh/hr	7.11
3.	Site No. 1 Crossing (near kidwainagar)	M	1994 veh/hr	174.70
		E	1857 veh/hr	171.10
4.	Kidwainagar Crossing	M	1849 veh/hr	136.30
		E	1648 veh/hr	9.80

M → Morning peak period

E → Evening peak period

From the table we can see that average delay to vehicles for Site No.1 Crossing for both morning and evening peak hour is very high. This is because of certain assumptions made in the model regarding queue discipline (for example it is assumed that all types of vehicles are moving in a queue and no overtaking is allowed at intersection). But in general practice the above assumptions are not followed by some light vehicles like bicycle,

scooter etc. which try to reach the front of the queue by moving sideways while waiting in queue. It has also been observed that due to large volume of bicycle traffic (about 45% of total traffic) the delay to the traffic stream is more. Simulation model is modified to reduce the delay by considering a separate lane for bicycle and it is assumed that at the most four bicycles can move together in parallel in that lane. It implies that for first four vehicles in the queue, the queue length is zero. In the modified model no PCU factors were used and the total volume has been considered. Later the program was run and average delay of vehicles for both bicycle and non bicycle lanes is found and listed in the following table.

Table 5.5 Results from the modified model

Sr. No.	Intersection	M/ E	Total Volume	Average delay in Seconds	
				Bicycle lane	Other lane
1.	Kidwainagar Crossing	M	2188	6.76	7.62
		E	2388	8.02	11.23
2.	Site No. 1 Crossing	M	2860	34.67	39.20
		E	2572	23.15	23.04
3.	Kalyanpur T- Intersection	M	1800	5.72	4.44
		E	1887	4.94	5.25

From the above table we can see that the average delay for Site No.1 Crossing has drastically decreased and delay to the vehicle seems to be quite close to the practical situation and that the model output seems reasonable.

CHAPTER SIX

RESULTS, DISCUSSION AND CONCLUSIONS

6.1 RESULTS

The results obtained by simulation model of freeway merging area is already discussed in section 3.6 of Chapter three. Further the results of simulation model of T-intersection and four way intersection are discussed in this chapter. The major effort in this study has been to find the delay to vehicles crossing or merging at an intersection.

In the case of T-intersections, as there is priority to major road vehicles delay is calculated to minor road vehicles. Vehicles of minor road can have both left or right turns. Left turn delay and right turn delay to minor road vehicles is separately considered. Average total delay, and average left/right turn delay are calculated. This delay is calculated for different combinations of traffic flow and graphs are plotted between average delay and side street vehicle volume for a fixed major road flow. From Fig.6.1-6.4 between average delay (in seconds) versus flow on side street road (number of vehicles/hr), it can be seen that for a fixed major road flow the delay increases with the increase in minor road flow. Moreover it is seen that the rate of increase of delay increases with the increase in minor road flow.

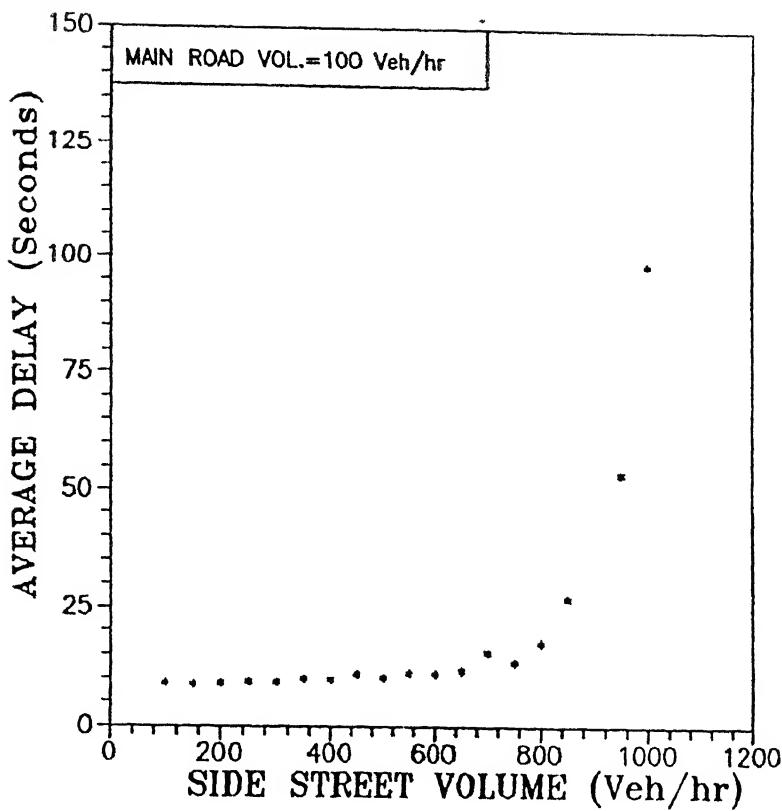


FIGURE 6.1

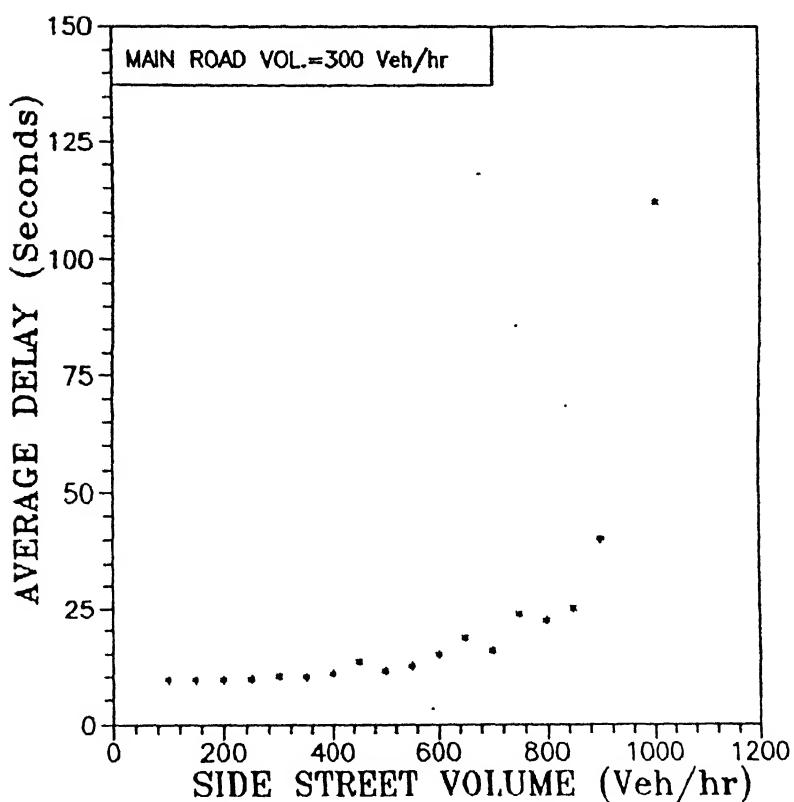


FIGURE 6.2

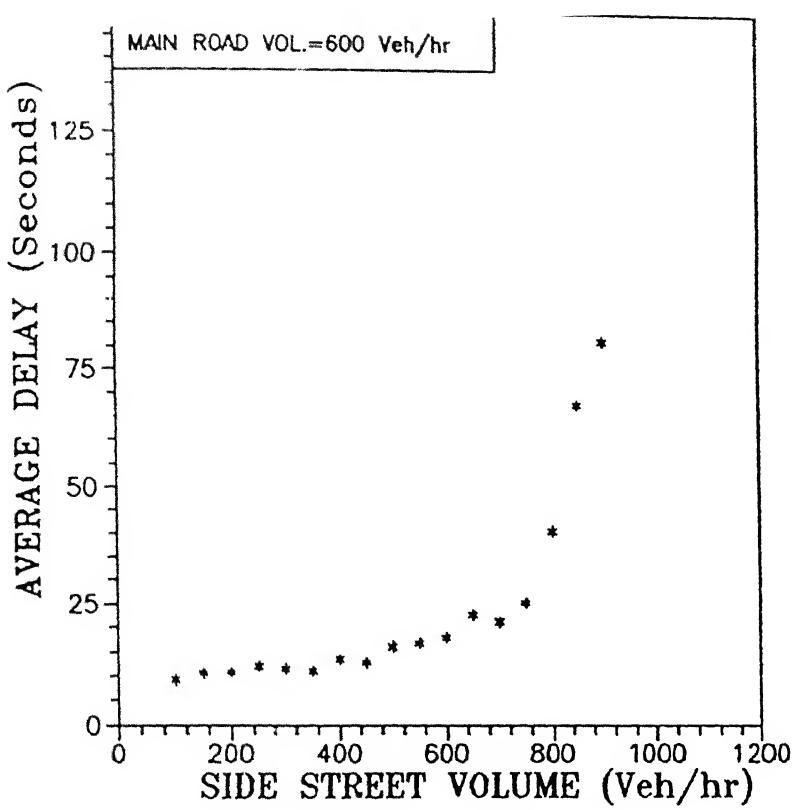


FIGURE 6.3

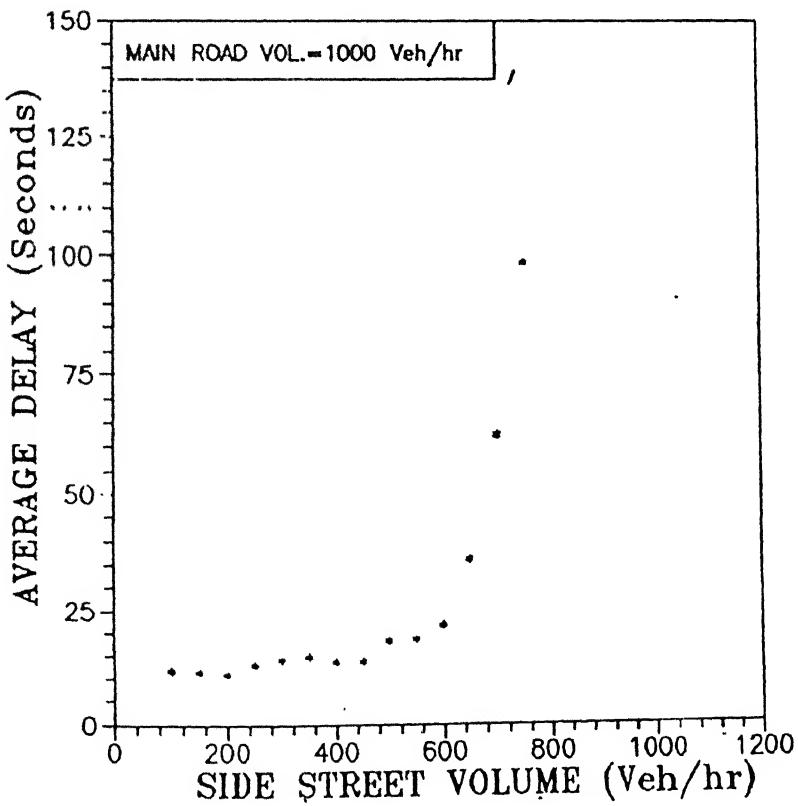


FIGURE 6.4

beyond certain flow. It can also be observed from Fig.6.5 that for a fixed minor road flow the delay increases with the increase in the major road flow i.e. for the flow of 300 veh/hr on minor road the delay for major road flow for 100 veh/hr is 9.1 seconds (refer Fig. 6.1). Similarly for the same minor road flow delay for major road flow of 300 veh/hr is 10.2 seconds refer Fig. 6.2 and so on.

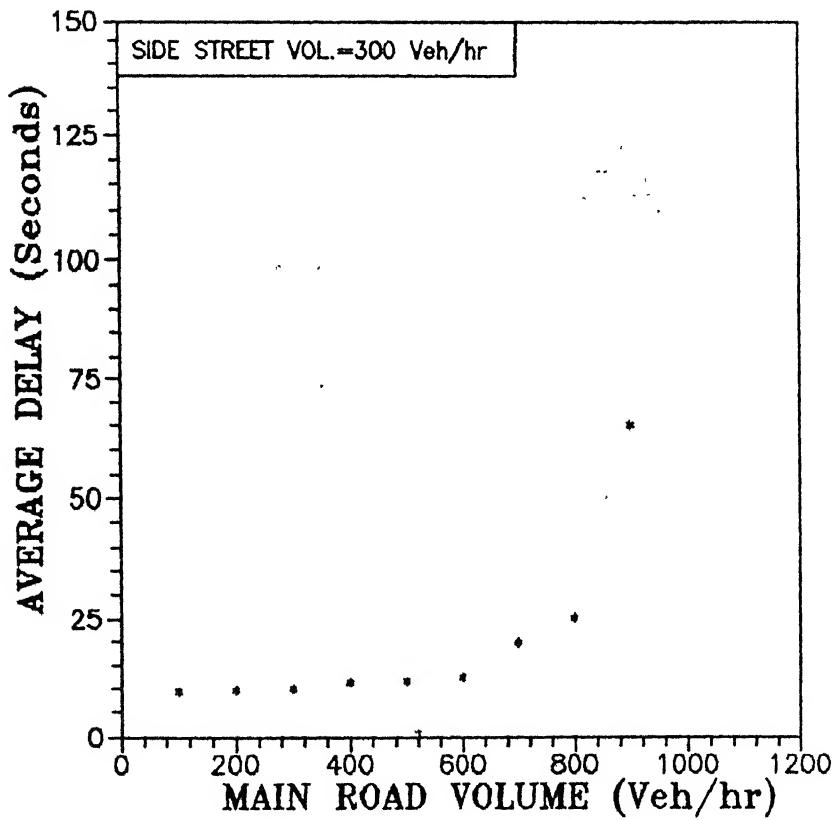


FIGURE 6.5

Further a graph, shown in Fig.6.5, is plotted between average delay and major road flow for fixed minor road flow of 300 vehicles/hr. Fig.6.6 shows relationship between total intersection capacity and average delay to intersection. With the help of this graph one can find the capacity of an intersection.

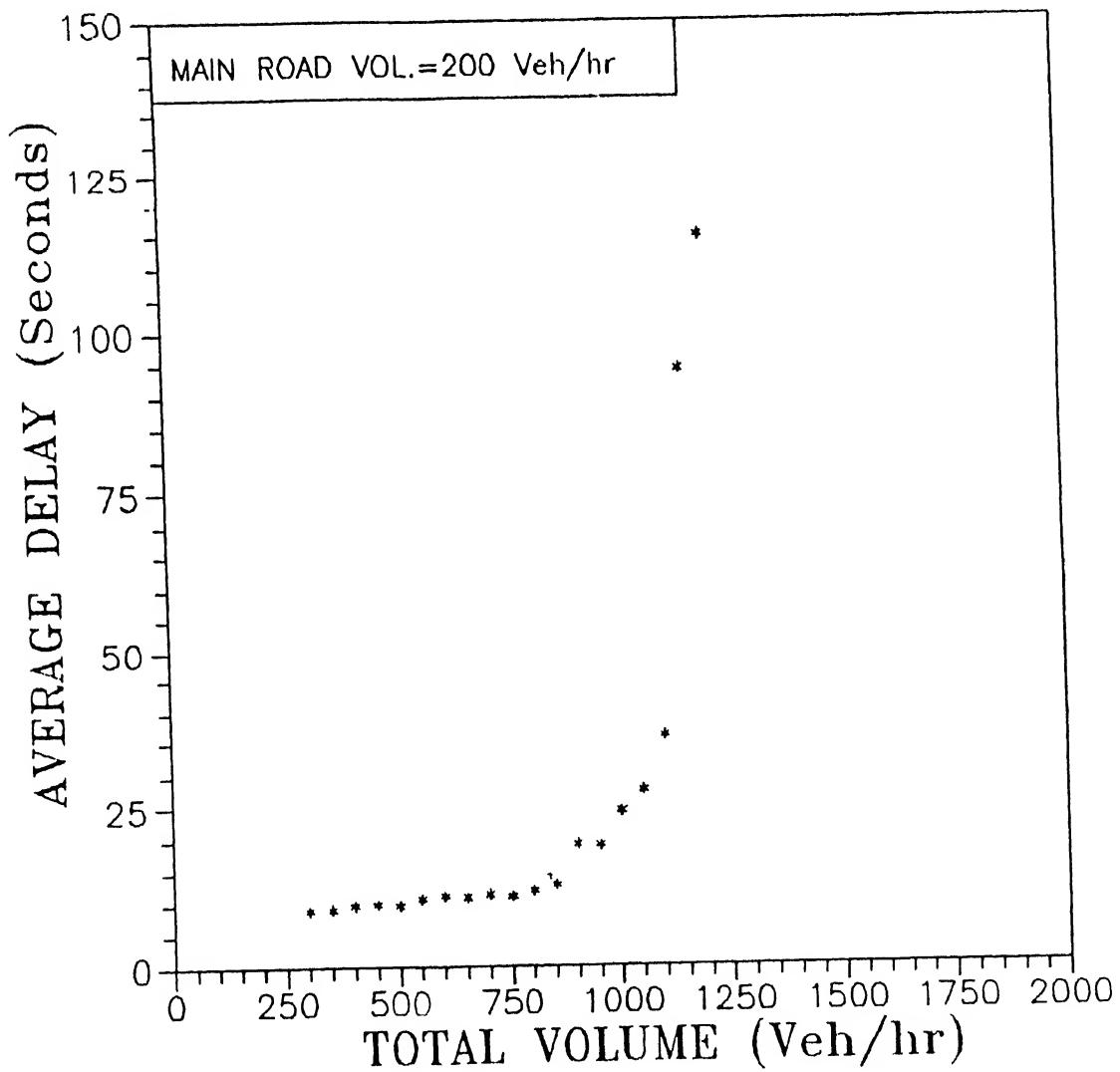


FIGURE 6.6

In the model for four way stop sign intersection, all the vehicles having equal priority, each is subjected to delays. In this model the major factor to check the performance of an intersection is average delay to vehicles. Graphs are plotted for average delay to vehicle versus total intersection volume. From Fig. 6.7 to 6.10, it can be seen that average delay to intersection increases exponentially with increase in traffic volume. From the above graphs it is clear that beyond some volume average delay tends to increase very rapidly, and this volume is called capacity of an intersection. Fig. 6.11 is a graph between east-west (EW) volume versus east-west (EW) delay and north-south (NS) delay for a fixed north south volume. It is seen from graph that for a fixed NS volume with increasing EW volume rate of increase of EW delay is more than NS delay.

6.2 DISCUSSION AND CONCLUSIONS

Behaviour of traffic in the vicinity of the intersection is quite complex and it does not seem feasible to use analytical techniques. It is due to this reason that a computer simulation model for the study of performance at intersection is formulated. Simulation results show a close agreement with field observation and are thus validated for real life situation.

The model has the potential of meeting needs and the power to analyse this class of problems. The output of simulation includes the performance measures such as average delay time for

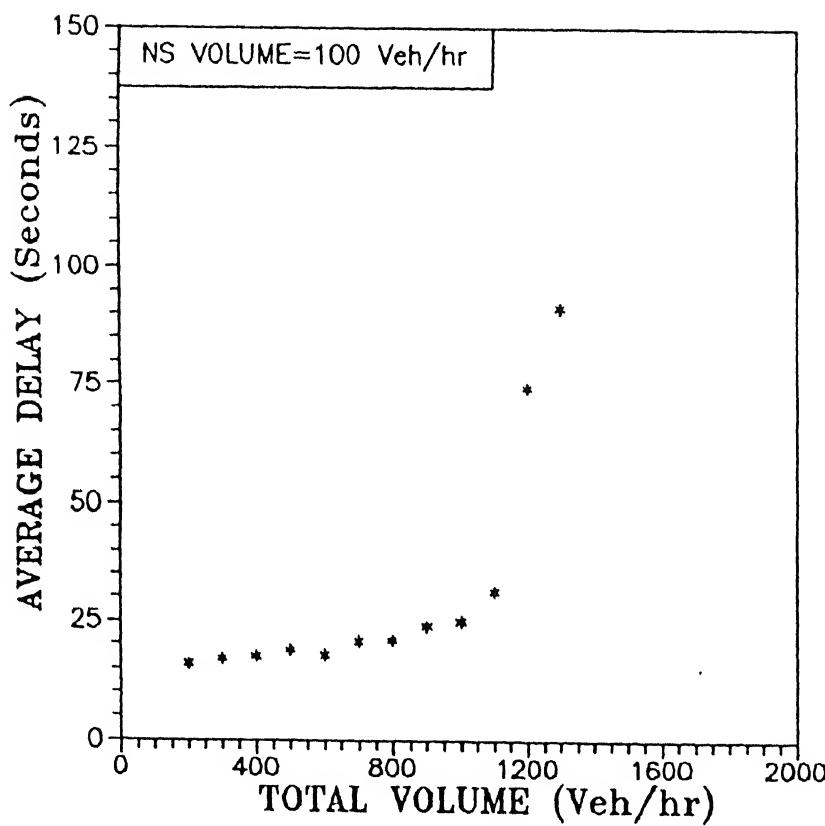


FIGURE 6.7

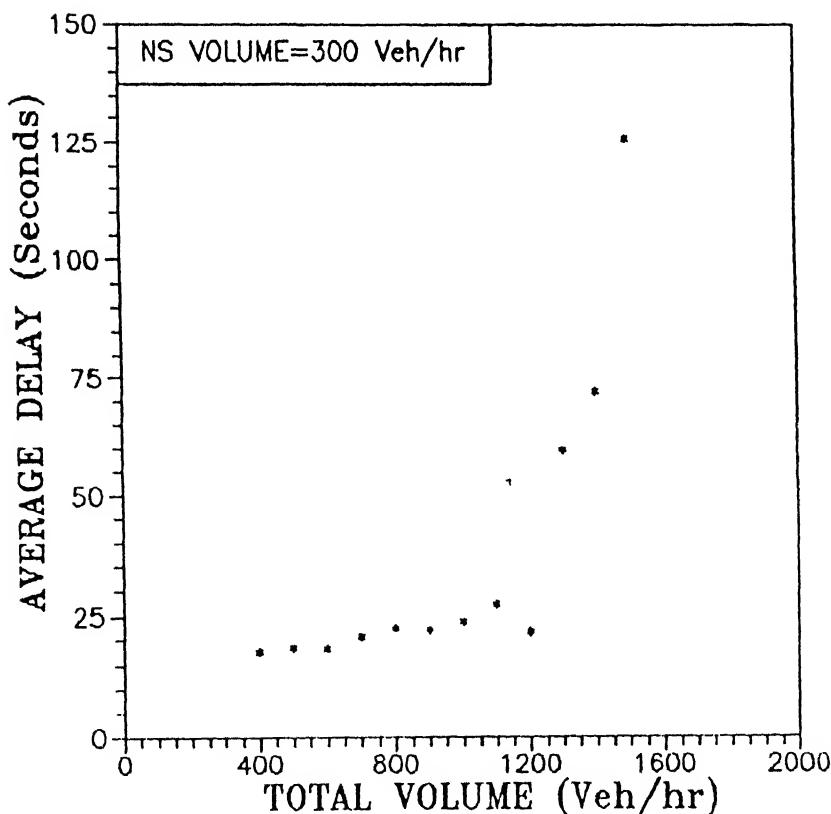


FIGURE 6.8

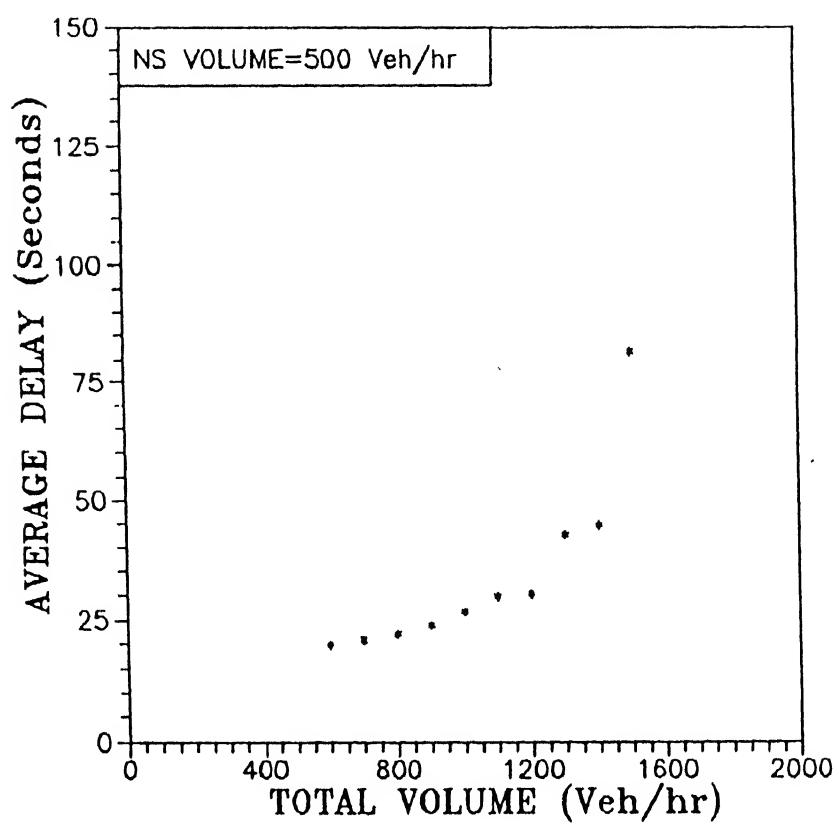


FIGURE 6.9

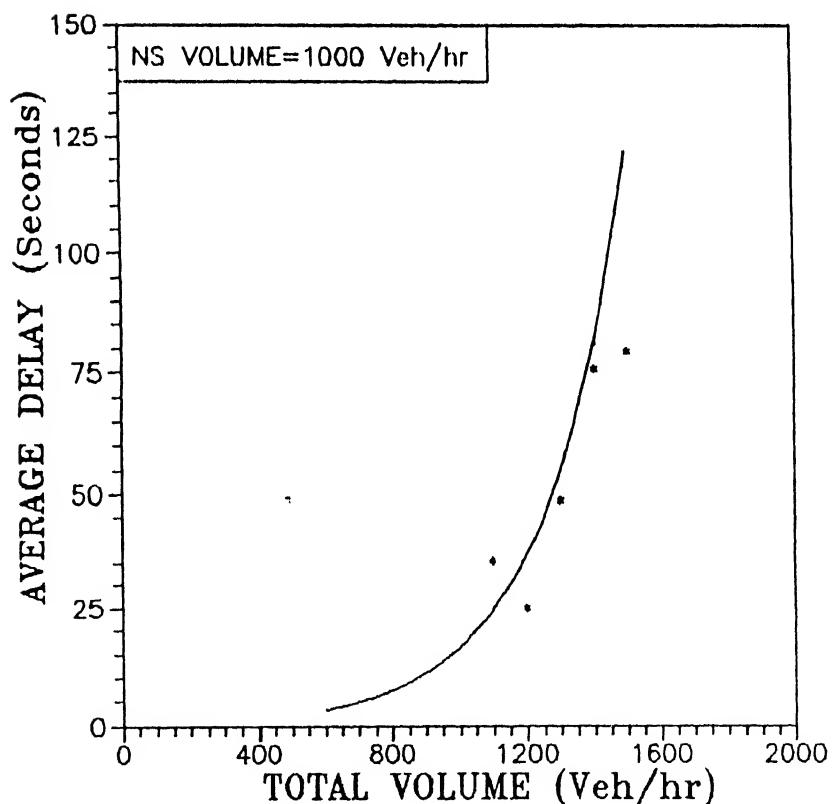


FIGURE 6.10

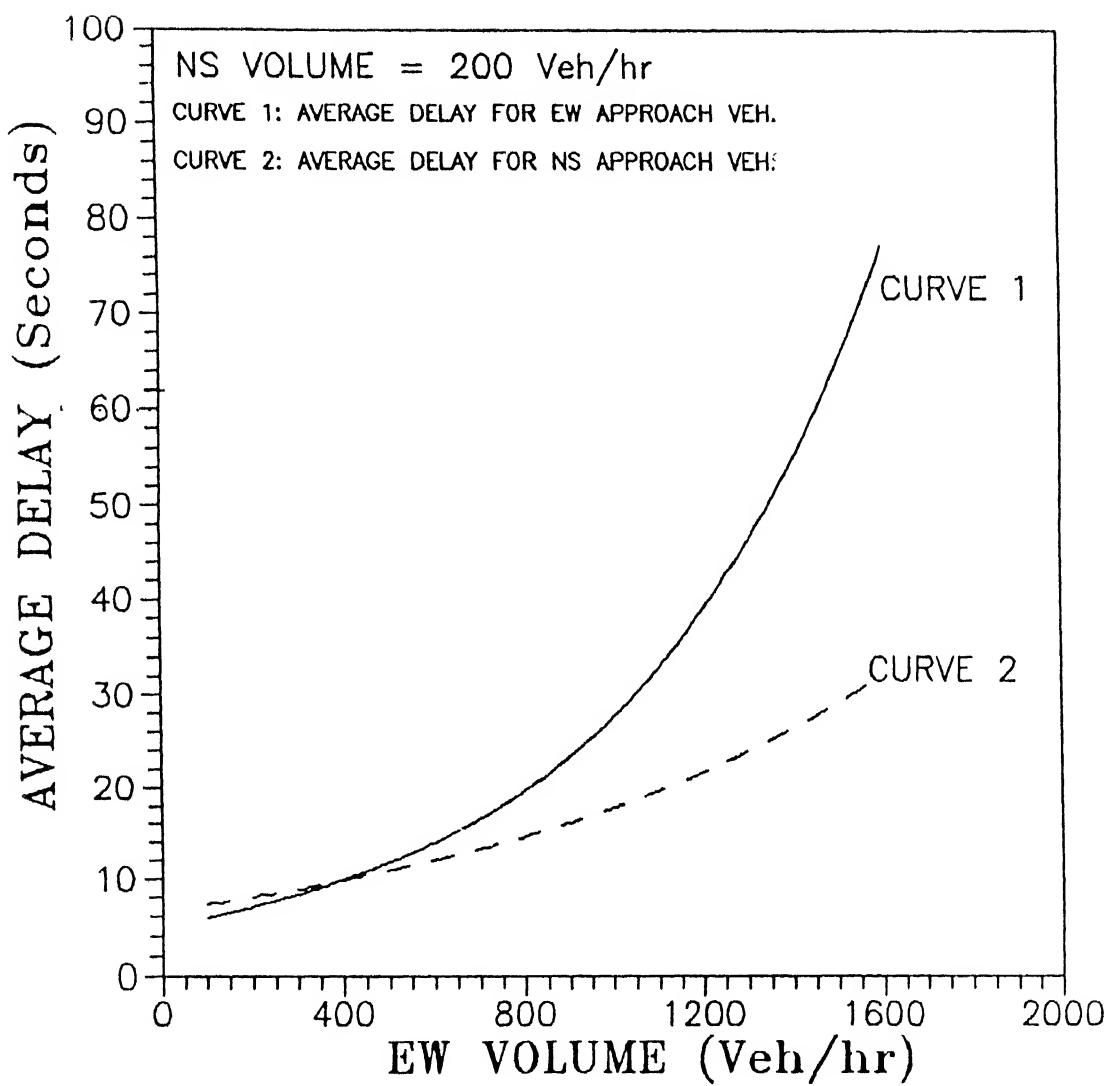


FIGURE 6.11

delayed vehicles, average delay time for all vehicles, number of different types that are delayed and their respective delay times and average queue length at all approaches. The model has been face validated by comparing the simulated results with observed data. The properties selected for validation is average delay to vehicles at intersection. From all the above graphs it is obvious that delay to vehicle increases rapidly beyond certain increase of flow.

Other measures of effectiveness of the model such as capacity calculation of intersection and fuel consumption model for an intersection can be formulated as follows:

The capacity of an intersection can be found from observing the Fig. 3.8 for ramp intersection, Fig. 6.6 for T intersection and Fig. 6.8 for four way intersection. As traffic volume tends to capacity of intersection average delay tends to infinity. So capacities for all simulated intersections estimated by this model is listed in following Table 6.1.

Table 6.1 *Estimated Capacities from model*

Sr. No.	Intersection	Capacity (veh/hr)
1.	Ramp intersection	2250
2.	T intersection	1250
3.	Four way stop sign intersection	1500

Fuel consumption model for unsignalised intersection can be expressed in terms all three types of delay components, such as deceleration delay, queueing delay, and looking for gap delay. So extra fuel consumed by vehicle crossing the intersection can be given by the following equation:

$$F_i = k_1 * D_d + k_2 * D_q + k_3 * D_l$$

where D_d is deceleration delay,

D_q is queueing delay,

D_l is looking for gap delay,

and k_1, k_2, k_3 are constants

Terms D_d , D_q , D_l are known from the model. The constant k_1 , k_2 , k_3 can be estimated if field data about extra fuel consumption at intersection is available. This estimate will be different for different class of vehicles.

A validated computer simulation model of vehicle performance at the unsignalised intersection may be of considerable value in suggesting techniques for designing intersections and establishing traffic regulations. It will also give an idea as to at how much flow the intersection performance considerably reduces and as a matter of fact we can say that intersection has failed at or above that particular flow. The complexity of these situations, however, cannot be handled adequately by mathematical algorithms, and prototype models are required for that purpose.

6.3 SUGGESTIONS FOR FUTURE WORK

(1) For any simulation model to be used, it is to be validated accurately. In the absence of detailed delay of vehicles the model could not be validated exactly. The model thus needs to be validated using the exact field data.

(2) In calculating the deceleration delay only deceleration rate is taken as criteria. However it depends upon driver behaviour (PIEV theory), efficiency of brakes, frictional resistance between the road surface and tyres and the slope of road surface, if any.

(3) Gap acceptance data, which is taken from the Yale Bureau of Highway Traffic needs to be for all types of intersection for Indian road conditions.

(4) Drivers reaction time, which is not considered in the subsequent studies, needs to be collected from field observation.

(5) Parameters for fuel consumption model given for unsignalised intersection must be estimated by having field observations for all types of intersections and vehicles.

(6) In this study overtaking in intersection zone has not been permitted, however, there is a need for further investigations on this technical data problem.

(7) The model should be integrated for major network simulation so that the cost pertaining in the simulation of the actually existing conditions can be determined.

(8) Effect of pedestrian flow at intersection should also be considered to check the performance of an unsignalised intersection.

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